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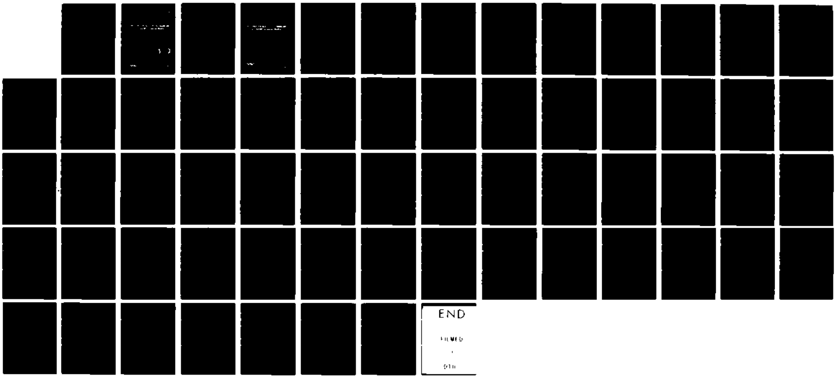

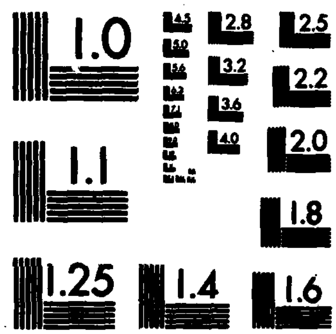
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Remotely Piloted Vehicle: Application of the GRASP Analysis Method

William L. Andre and J. Bradley Morris

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NASA
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Remotely Piloted Vehicle: Application of the GRASP Analysis Method

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REMOTELY PILOTED VEHICLE: APPLICATION OF THE GENERAL RELIABILITY ANALYSIS SIMULATION PROGRAM

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SUMMARY

This is a consolidation of the preliminary work done in the application of a General Reliability Analysis Simulation Program (GRASP) for the Lockheed Remotely Piloted Vehicle (RPV) system, being developed for the United States Army.

The model simulates the field operation of the RPV system. By using individual component reliabilities, the overall reliability of the RPV system is determined. The results of the simulations are given in operational days. The model represented is only a basis from which more detailed work could progress.

The RPV system in this model is based on preliminary specifications and estimated values. The scope of this report demonstrates the use of GRASP from basic system definition, to model input, and to model verification.

INTRODUCTION

This report is a consolidation of the preliminary work done in the application of a General Reliability Analysis Simulation Program (GRASP) for the Lockheed Remotely Piloted Vehicle (RPV) system, being developed for the United States Army.

This paper demonstrates the process used to create the RPV model, to change the model into the RPV data set, to validate the RPV model/data set, and the steps necessary to interpret the output. The results of the GRASP simulation are expressed in successful operational days. A successful operational day is defined as the completion of three 3-hr mission flights in a 12-hr period. Each simulation begins with five new air vehicles and all ground equipment in operational status.

The conclusion of the report emphasizes the versatility of using GRASP, and the status of the RPV data sets.

ABBREVAITIONS

ADT	air data terminal (part of MICNS communications package)
AF	air frame
ARA	air reference assembly
AV	air vehicle
AVIM	air vehicle intermediate maintenance
AVO	air vehicle operator
AVOC	air vehicle operator console
AVUM	air vehicle unit maintenance
EPS	electrical power system
FCEP	flight control electronics package
FLT	flight
GCS	ground control station
GCSIU	GCS interfacing unit
GEN	generator
GRASP	generalized reliability analysis simulation program
GSE	ground support equipment
IR	infrared (landing system)
LA	launcher assembly
LMSC	Lockheed Missiles and Space Company
LRU	line-replaceable units
MAIM	main GCS computer
MC	mission commander
MCO	mission commander operator
MCOC	mission commander operator console
MICNS	modular integrated control navigation system
MP	mission payload
MPC	mission payload operator console
MPO	mission payload operator
MPS	mission payload subsystem
MS	maintenance shelter
MTBF	mean time before failure
NAV	navigation
NPV	navigation display unit
PROP	propulsion assembly
REC	recovery subsystem
RGT	remote ground terminal
RPV	remotely piloted vehicle
TTF	time to fail
TTR	time to repair

GRASP II COMPUTER PROGRAM REVIEW

GRASP II (Version II) is a Fortran-based computer program which can simulate a reliability-based system operation consisting of time and cost. GRASP is a method by which a system can be represented by certain parameters and logical relationships, and be shown graphically as a network diagram presenting the reliability configuration of that system.

In order for a model to be developed, certain building blocks must be understood. GRASP network diagramming is based on two basic elements: nodes and arcs. Nodes are events in the system, such as a failure of a component, end of a repair, or completion of any other type of activity. Nodes are denoted by circles in which N1 is the number of pulses needed to release the node the first time and N2 is the number of pulses needed to release the node at subsequent times. Arcs, or branches, represent time-consuming activities, such as time-to-fail (TTF), time-to-repair (TTR), or any event precedence relationship in the system. Event precedence relationships have no duration, that is, they occur instantaneously. (See figure 1 for examples of nodes and arcs.)

This is a basic look at the GRASP network diagram. Further information can be obtained from the GRASP Users Manual, and it is recommended that the reader review and become familiar with GRASP if a more detailed discussion is required.

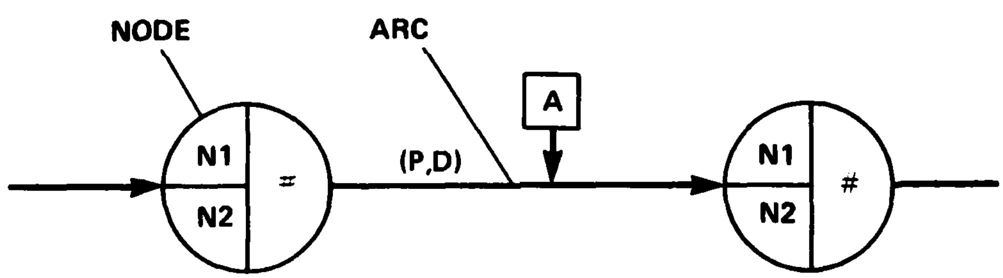

Figure 1.- Arc and node diagram.

COMPOSITION OF THE LOCKHEED RPV SYSTEM

The Lockheed RPV system consists of several components. These components divide the RPV system into key factors from which a network model can be made. In the following discussion, the overall mission function is first explained and then the individual components are described as they relate to the system.

The RPV system, as addressed in this report, is a combination of hardware and mission function. The hardware consists of mobile ground units used to support the air vehicles (AV) and the five AV's used for mission function.

The mission function consists of spotting and designating targets. The steps in this process include the prelaunch check (making sure all systems are working); the climb-out; the outbound flight; the mission stage where targets are found and identified; the inbound flight, which is similar to the outbound flight; and the recovery of the AV. The mission occurs between the outbound and inbound flight segments.

The hardware consists of seven mobile ground units:

1. Launcher truck
2. GCS (Ground Control Station)
3. Recovery truck
4. MS (Maintenance Shelter)
5. Crane truck (truck carries two AV's)
6. AV truck (truck carries three AV's)
7. Pickup truck

Trailers for transporting the Remote Ground Terminal (RGT) and two generators are also required.

The GCS controls the AV while the AV is in flight. It can also perform the checkout during prelaunch and monitor tests during a mission flight. The MS (Maintenance Shelter) is a field workshop for repairing the AV's, GCS, RGT, generators, launcher, and recovery truck.

The following description of the RPV system provides a working knowledge of the basic system characteristics as they relate to this report; it is public information, having been published in <u>Aviation Week and Space Technology</u> (vol. 112, no. 2, Jan. 7, 1980, pp. 54-63).

The major areas of reliability concern are between stages C to F (fig. 2), where C to D to E is system checkout, E to F is AV flight and mission operations, and F to "or" is the recovery of the AV. Although factors of emplacement leading up to state C can be modeled, a limit must be placed on the size of the RPV system being modeled by GRASP; therefore, the system of emplacement has been disregarded.

An objective of the model analysis is to simulate the operational limits of a fielded RPV unit, that is, how many days can the system operate (successfully) from a fresh start, where a successful day is defined as three successful mission flights being performed within a 12-hr period. Thus the RPV system baseline model revolves around prelaunch and flight of the AV's.

The day begins with an AV on the launcher ready for its prelaunch check. If it is determined that the AV fails the prelaunch check, the prelaunch is aborted. The model will start a removal (time 15 min) of the bad AV from the launcher and replace it (in 15 min) with a good AV from the ready-pool. If

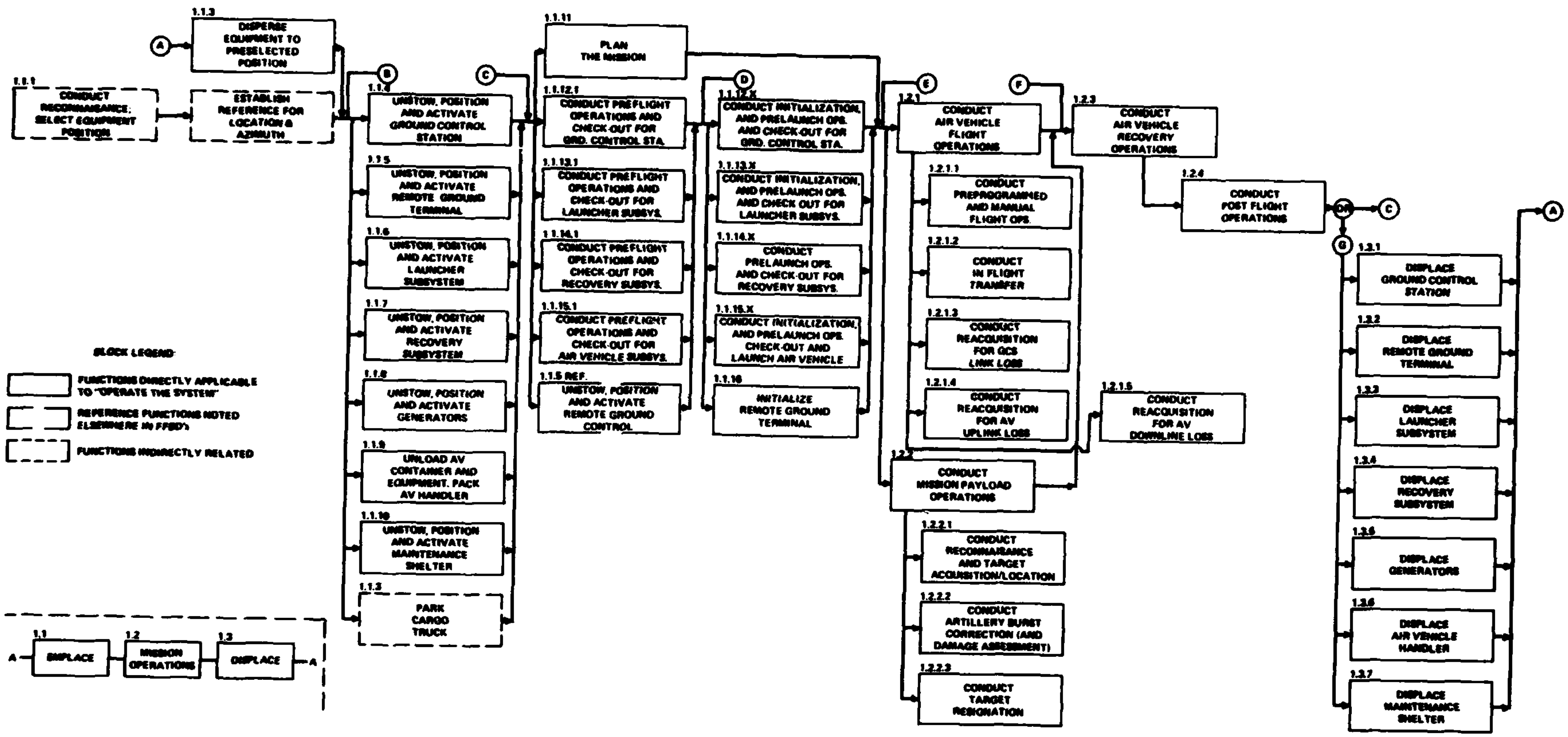

Figure 2.- Functional baseline.

the GCS or any other ground equipment fails and causes the launch to be aborted, the model aborts and waits until the failed component is fixed. Upon repair the model begins a new prelaunch check.

The GRASP model cannot detect multiple failures at a single time. For example, if the GCS and a generator fail at the same time, the GRASP selects the one that was coded in first into the program and selects that particular one as the failed component. In any case, this is not a problem because the failure rates are low to start with.

Using the above example, another assumption, based on low failure rates, is that if the GCS and generator fail at the same time, they go into repair at the same time. The modeled RPV system has only one Maintenance Shelter (MS) and multiple repairs are handled on a sequential priority basis.

The key functional paths used in the model are diagrammed in figure 3, which shows how the AV's are used in the system.

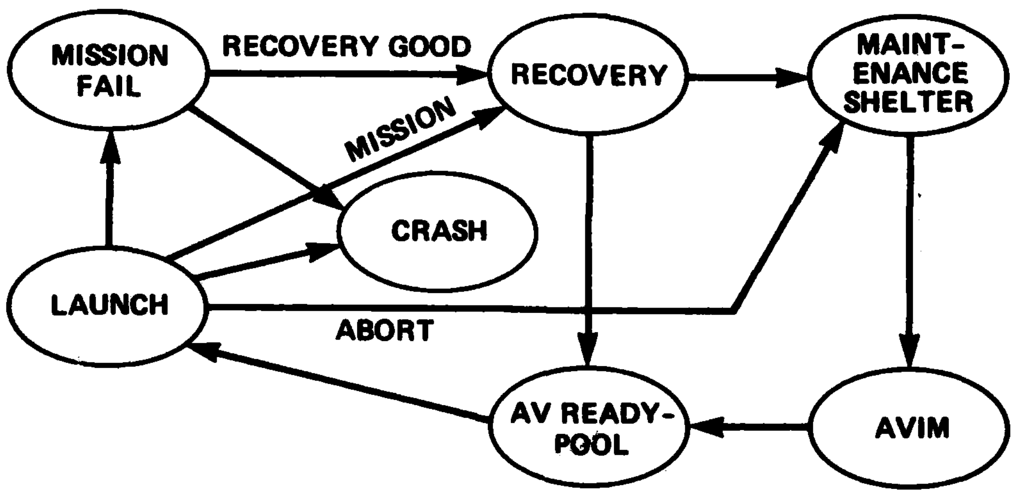

Figure 3.- Functional paths.

After being provided with some initial assumptions, a meeting was held wherein more refined assumptions were incorporated into the model. Those assumptions are listed below:

1. If GCS main computer fails during a mission, the mission is aborted and inbound and recovery paths are set up. Note that the recovery operates at lower values.

2. The laser is needed for the mission and is only used during the outbound flight for position updating.

3. The recovery stage of the mission flight can be successful with IR or MPS recovery systems. Note that only MPS is used when IR is down.

4. If a subsystem goes down, it goes into repair without delay. (Example: AV, GCS, RGT, GSE, LA, Recovery.) The probability of more than one subsystem being down at the same time is low.

5. Launcher and Recovery hardware will only fail in an active state.

6. GSE refers explicitly to power generators. Note that the remote ground terminal has its own generators.

7. Of the three different maintenance systems, each exhibits its own characteristics for isolation of problems.

A chart was made up showing the reactions of the possible failed components during possible events. This provided a framework upon which the complete RPV system was composed into functional elements. A GRASP network diagram is constructed from table 1. This topic will be discussed in the next section.

BUILDING OF THE GRASP NETWORK

In the previous section the RPV system was broken down into functional elements. The idea was to represent these functional elements as nodes (events) and arcs (timed activities). The key hardware elements are the AV, GCS, RGT trailer, generators, launcher assembly truck, and recovery truck.

For the reliability model and GRASP network model, the AV will be represented by seven subsystems.

1. MP: mission payload
2. FCEP: flight control electronic package and flight sensor package
3. ARA: air reference assembly
4. ADT: air data terminal
5. EPS: electrical power system
6. AF: airframe
7. PROP: propulsion assembly

Certain assumptions that pertain to the AV are described next. It was assumed that failure during prelaunch of any of the AV subsystems (1 through 7) would cause the launch to be aborted. This is then followed by removal of the failed AV (15 min) and its replacement on the launcher with a good AV from the ready-pool.

The AV subsystems were also modeled allowing for failure of the MP (mission payload) package during flight. This failure would result in the return of the AV with the proper sequencing time. Also, upon recovery of the AV with the failed MP, a reduced reliability of recovery occurs. Sequencing

TABLE 1.- FAILURE MODES FOR SUBSYSTEMS

Failure	Action					
	Prelaunch	Launch climb-out	Outbound	Mission	Inbound	Resources
Two of three consoles[a]	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
One of three consoles[a]	Repair recycle	Recovery	Inbound/ recovery	Inbound/ recovery	Recovery	No effect
Navigation display unit[a]	Repair recycle	Recovery	Inbound/ recovery	Inbound/ recovery	No effect	No effect
Main computer[a]	Repair recycle	Recovery	Inbound/ recovery	Inbound/ recovery	No effect	Recovery degraded mode
GCS I/U[a]	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
Launcher hardware	Repair recycle	No effect	No effect	No effect	No effect	No effect
Recovery hardware	No effect	No effect	No effect	No effect	No effect	AV lost
GSE	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
RGT[a]	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
MPS/TV	Repair recycle	Recovery	Inbound/ recovery	Inbound/ recovery	No effect	IR only
Laser	Repair recycle	Recovery	Inbound/ recovery	Inbound/ recovery	No effect	No effect
FCEP	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
ARA	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
Propulsion	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
ADT	Repair recycle	AV lost	AV lost	AV lost	AV lost	AV lost
IR	Repair recycle	No effect	No effect	No effect	No effect	MPS landing

[a]10-min delay to determine if equipment cannot be placed back into operational status.

time refers to the time needed for the return of an AV in the event of a failure. If the AV is on climb-out or outbound and a failure occurs, then the AV is returned. The time that the model has used to get the AV to the climb-out or outbound is assumed small. If the MP fails on the mission phase, then the model starts an inbound flight upon detection of the failure. Thus the 25-min period for the inbound flight is not negligible as was the case in the failure of the MP during climb-out or outbound flight.

The modeling of the other hardware elements is not as complicated as that of the MP. The AV subsystems are grouped together. As stated before, if any of these subsystems fail during the prelaunch, the launch is then aborted and AV replacement procedures are started. If the other items fail during flight (excluding MP) then the model will crash the AV at the time of failure and begin the launch of a new AV.

Upon successful launch of the AV, another AV from the AV ready-pool is placed on the launcher. This process is done so that if the AV in the air fails and crashes, then the AV on the launcher is ready for its prelaunch checkout.

During the mission flight the AV is continually checked as two separate systems: (1) the mission payload, and (2) items 2 through 7 above (p. 7). If any of these systems fail, the model will properly select the path for that failure to be recognized.

The GCS has 10 major subsystems for its model. Of these 10, only 6 are necessary for proper modeling: the three consoles, the GCS Interface Unit (IU), the navigation display, and the main computer.

The omission of the communications equipment is justified because there is adequate redundancy in that system and because the communications network does not directly affect the critical operation of either the RPV or AV.

The AVO (air vehicle operator) console, MPO (mission payload operator) console, and the MCO (mission commander operator) console are assumed to operate in a somewhat redundant fashion. That is, if one console fails then the AV can still be controlled (to a limited extent) and return of the AV is initiated. If two consoles fail, control of the AV cannot be maintained and the AV is lost. There is a 10-min timer that sets the limits for repair of the GCS and reestablishment of communications with the AV. These 10-min timers are not only for the consoles but also for other GCS subsystems in the model.

Of the six components used to model the GCS there are only two failures that result in loss of the AV: a two-console failure (as stated before) and loss of the GCS interface unit computer.

If a model component fails and is not sent immediately to repair, a repair facility is designated for that component. (Note that this is based on low failure rates.) For the GCS model, GRASP generates only one set of failure data at the start of the simulation. When a GCS subsystem fails,

GRASP generates a new mean time between failure (MTBF) for that particular subsystem only, unlike the AV model in which a new set is derived for each flight at prelaunch.

If the GCS does go down and an AV is lost, the model waits until the GCS is back up (arc 141-142 value #31) before starting a prelaunch check (node 6 to start prelaunch at node 2). Node 6 monitors the status of the GCS from node 152. When node 6 releases then it is known that an AV is on the launcher and that the GCS is ready to do a prelaunch.

VERIFICATION PROCESS

As with any program, experience in debugging is an essential element when input errors or logic errors surface. Both errors are difficult to correct, but finding the logic errors seems to be more challenging. GRASP has an option that is very useful in finding these logic errors. It is called the trace option, as specified on the first input card. The trace option gives the user a printout of the step-by-step pulse actions that occur in the model.

After the model has been diagrammed, it must then be incoded in the proper order for input into the GRASP program. The best process for checking the input is a node-by-node, arc-by-arc review. This process is most effectively done by two persons: one to read the node from the network diagram and the other to check it off on the computer printout. This process checks for input errors that may have occurred.

Next, the trace option is employed to analyze the output and validate the pathway of the pulse. In validating the model, errors surface easily and can be identified quickly. In one example, the trace option located a misplaced arc, which was causing a pulse to split in two. After locating the problem, it was soon corrected. The trace option, furthermore, follows the logic pattern of the model, thus providing an easy way to check for logic errors.

SAMPLE INTERPRETATION

A total of 14 different model-system configurations were addressed, each evaluated on a nodal-observation basis. The frequency of a node's occurrence was recorded on a cumulative basis. Other information was provided such as minimum time of occurrence, maximum time of occurrence, and standard deviation. For our particular model, only the number of observations was important. Other features could be incorporated, but because of the simplistic nature of the model they were omitted. Thus the number of observations could be converted into the number of days the RPV system is operational. A sample run follows, which serves to demonstrate the method of interpretation.

Node	Number of observations
5	27
182	23
299	50

Number of observations (node 5) = 27
Number of simulations = 100
27/100 = 27%

Nodes 5 and 182 show a system-failure situation, with the nodes indicating the cause or source of failure. Node 5 was observed 27 times in 100 simulations, indicating a 27-percent occurrence due to depletion of available air vehicles. Node 182 was observed 23 times, indicating a 23-percent occurrence due to incomplete 3-hr missions in the 12-hr periods. Node 299 (indicating successful missions) was observed 50 times in 100 simulations, showing 10 successful operational days without failure of the RPV system.

RECOMMENDATIONS

The system model discussed in this paper is only a base from which more detailed work could progress. Significant improvements might include:

1. Adding cost to the model. Although not specified in this report, additional cost requirements and values could be assigned after preliminary research.

2. Varying the mission time. This model uses a maximum time of 3 hr (plus 5 min prelaunch) to perform a mission scenario. A routine could be designed to vary the mission time between 1 hr and 3 hr.

3. Modeling the subsystems past the line-replaceable units (LRU's) to the board level or part level. This would provide far greater accuracy in the function and operation of the system.

4. Finding the average number of operational days. This model now determines the number of operational days until three successful flights cannot be completed within 12 hr. The model could be altered to determine, for example, that in 100 days, 80 are operational (i.e., producing successful missions) and 20 are failures.

At the conclusion of this project, additional features were requested from Lockheed, but there was no time to implement them. However, Lockheed suggested changing the failure rate for the AV subsystem so that a percentage of the failures would cause the AV to crash. Figure 4 shows the present failure monitor features of the AV subsystem, and figure 5 shows the effects of changing the features to accommodate a percentage of failures.

The RPV system in this model is based on specifications and estimated values, and the reader should bear in mind that corrections of data values or modifications may be necessary as time goes on. It should also be noted that the status of the model presented in this report is by no means indicative of the operational status of the RPV system under development at LMSC.

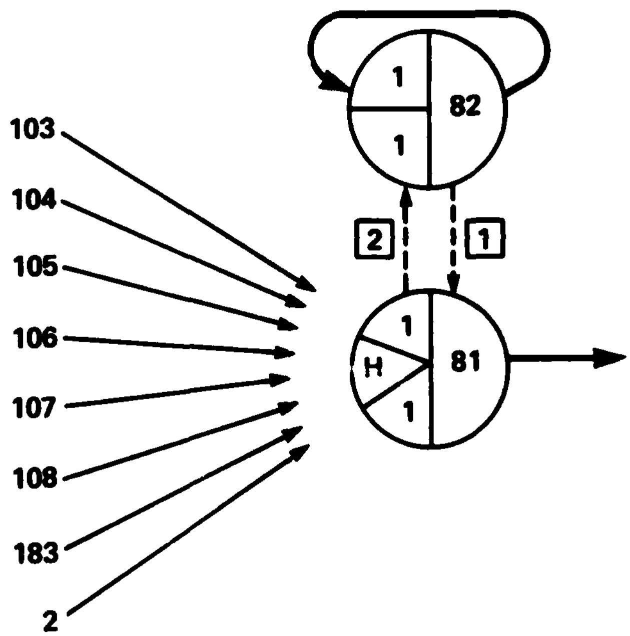

Figure 4.- Current AV subsystem.

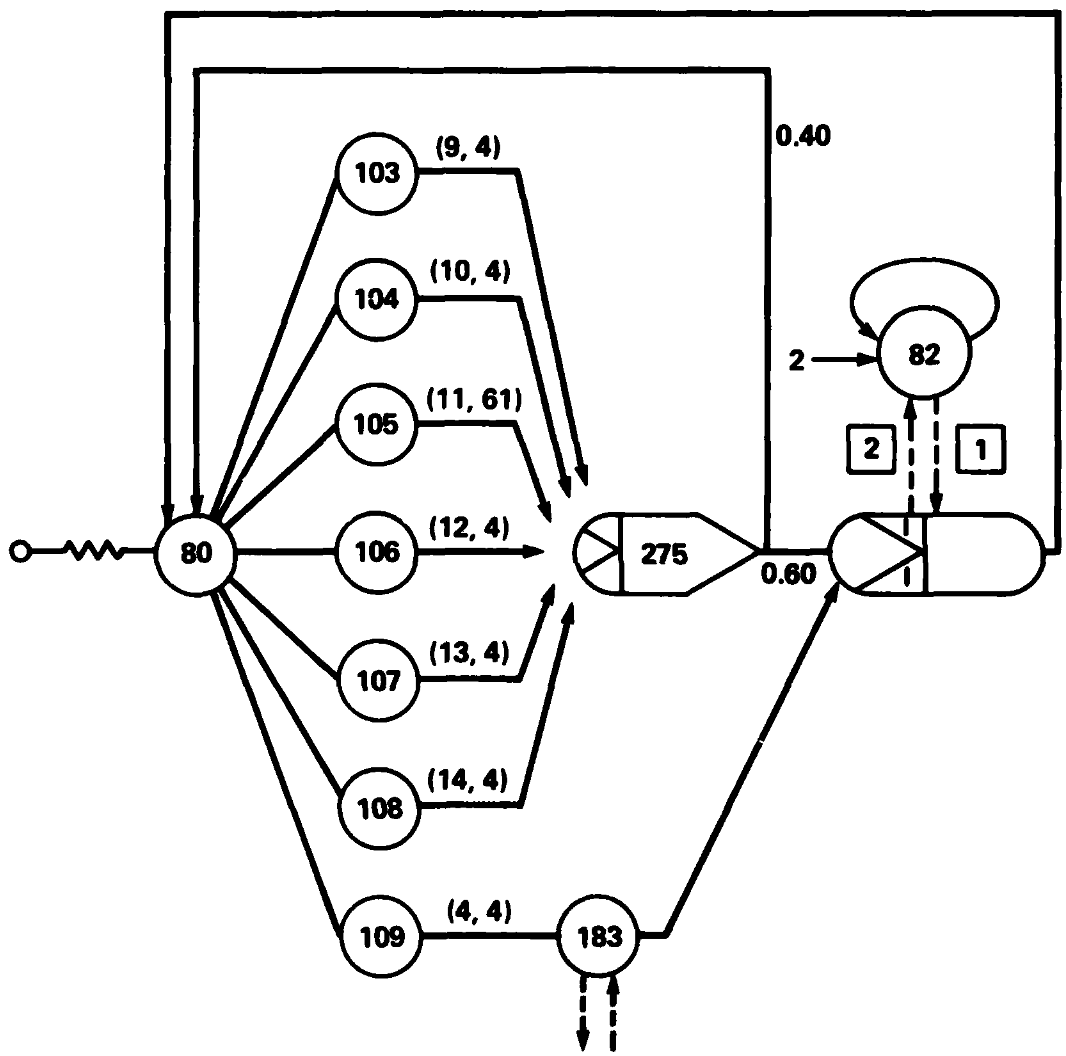

Figure 5.- Proposed modifications to AV subsystems.

APPENDIX A

NODE DIAGRAMS

The node diagrams are a pictorial analysis of the GRASP-RPV model. The mainline model consists of figures 6-9. Figures 10-13 show other system and support equipment.

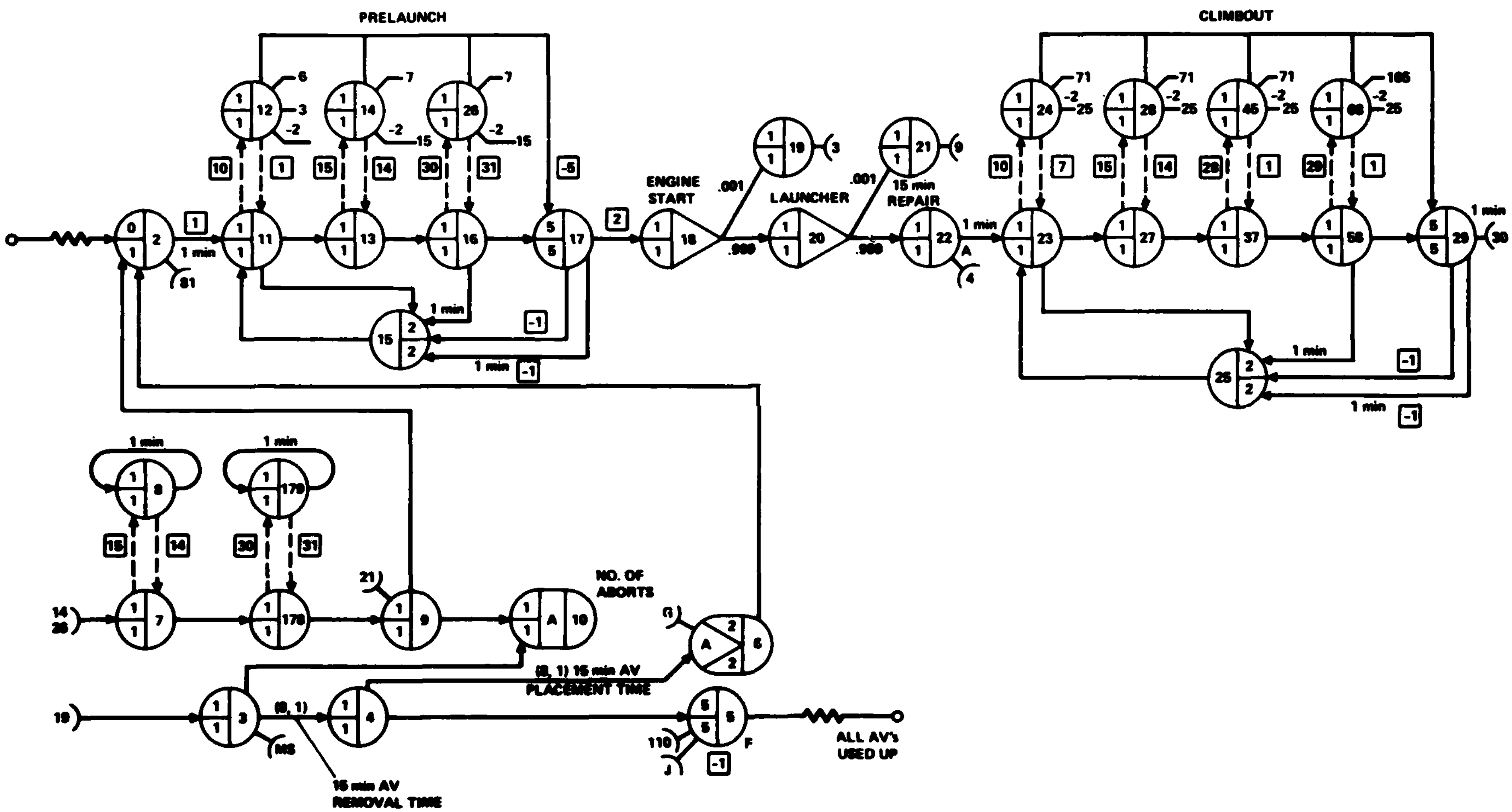

Figure 6.- Prelaunch, climbout.

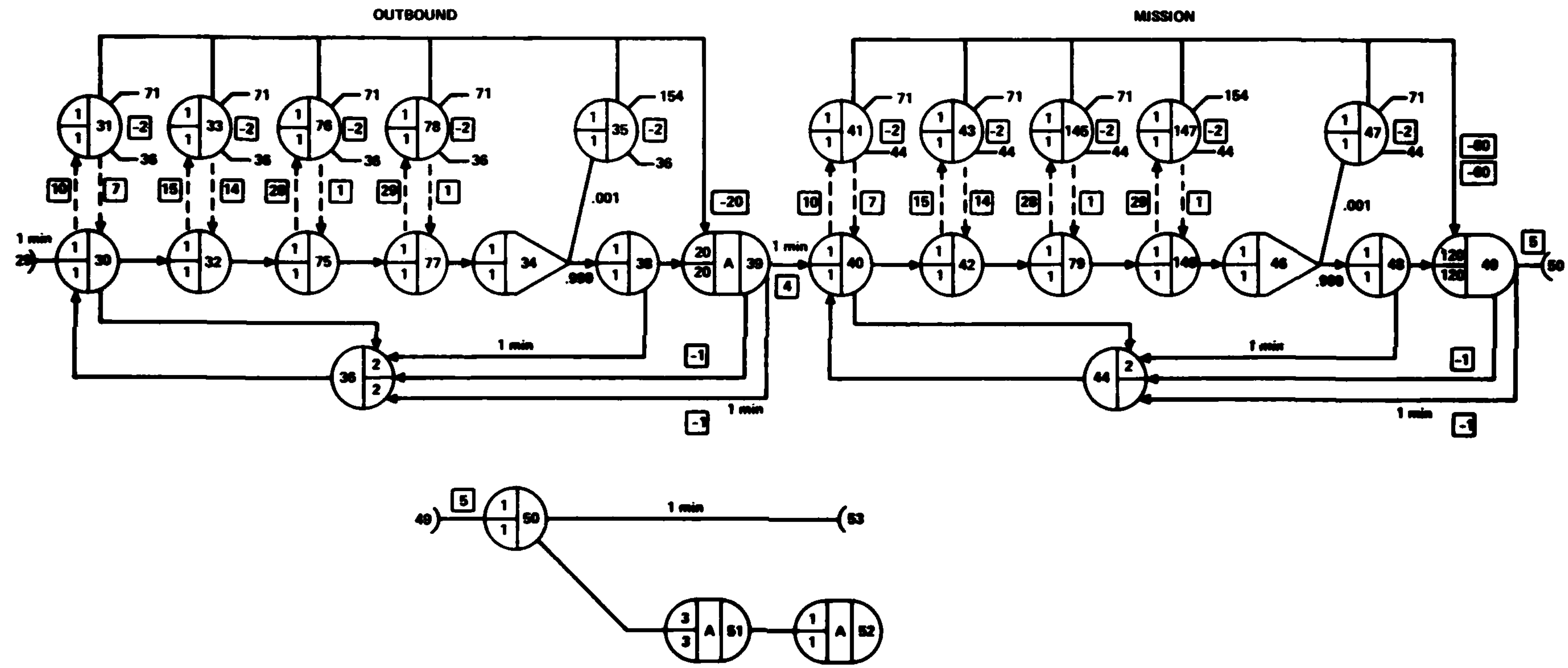

Figure 7.- Outbound, mission.

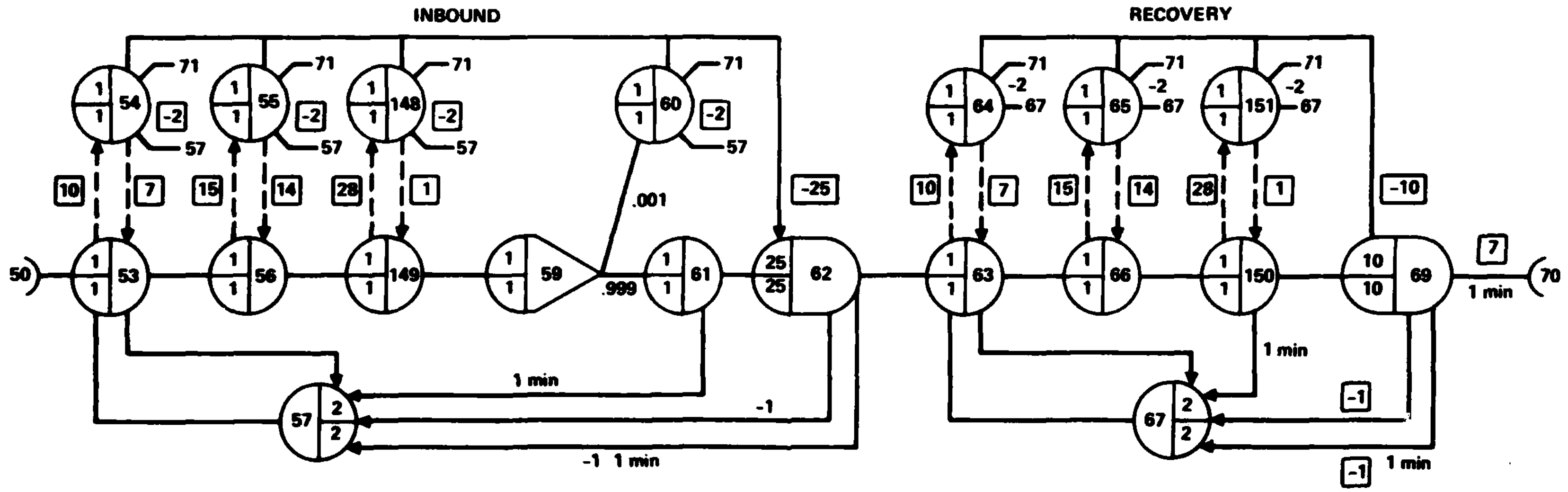

Figure 8.- Inbound, recovery.

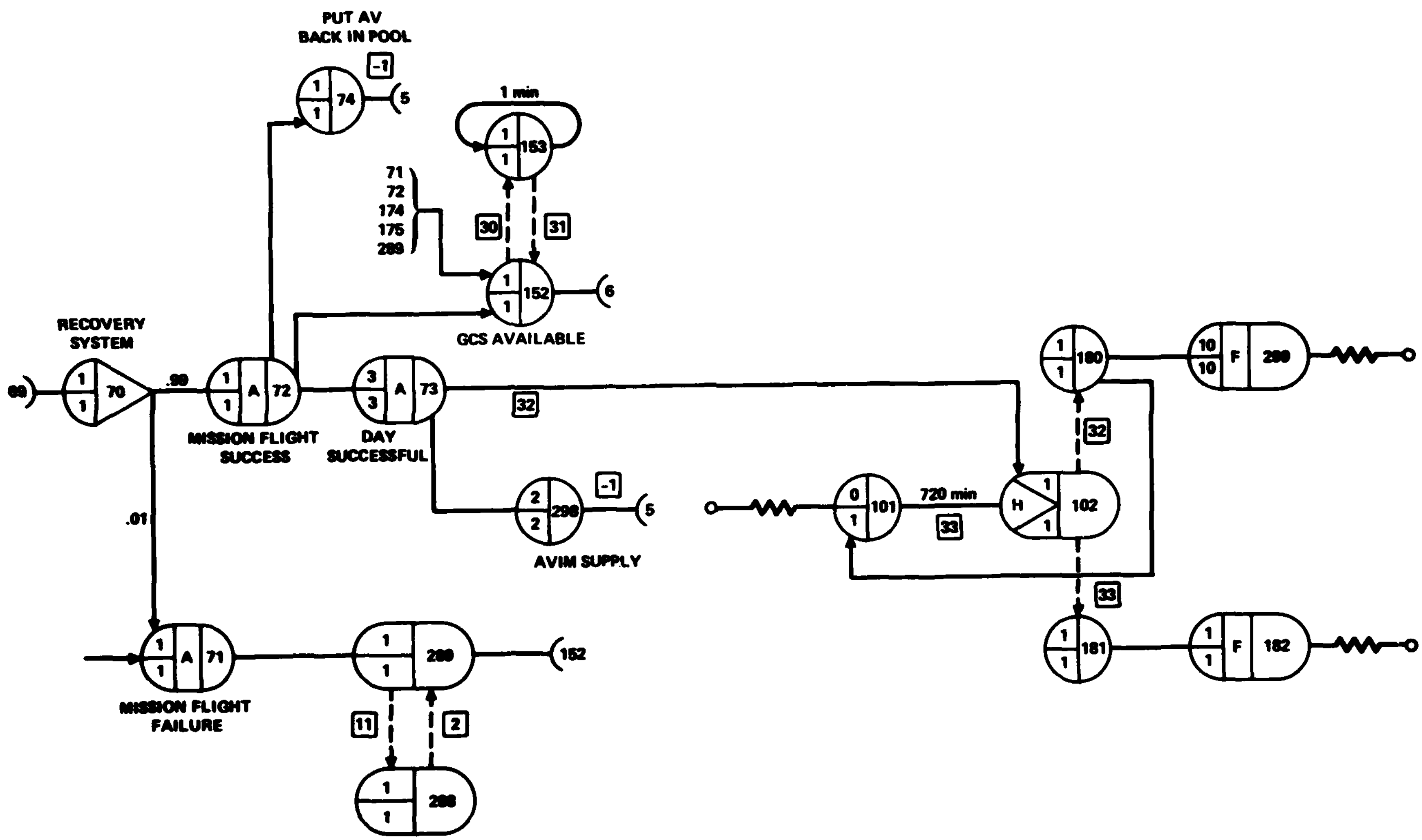

Figure 9.- Recovery, timer.

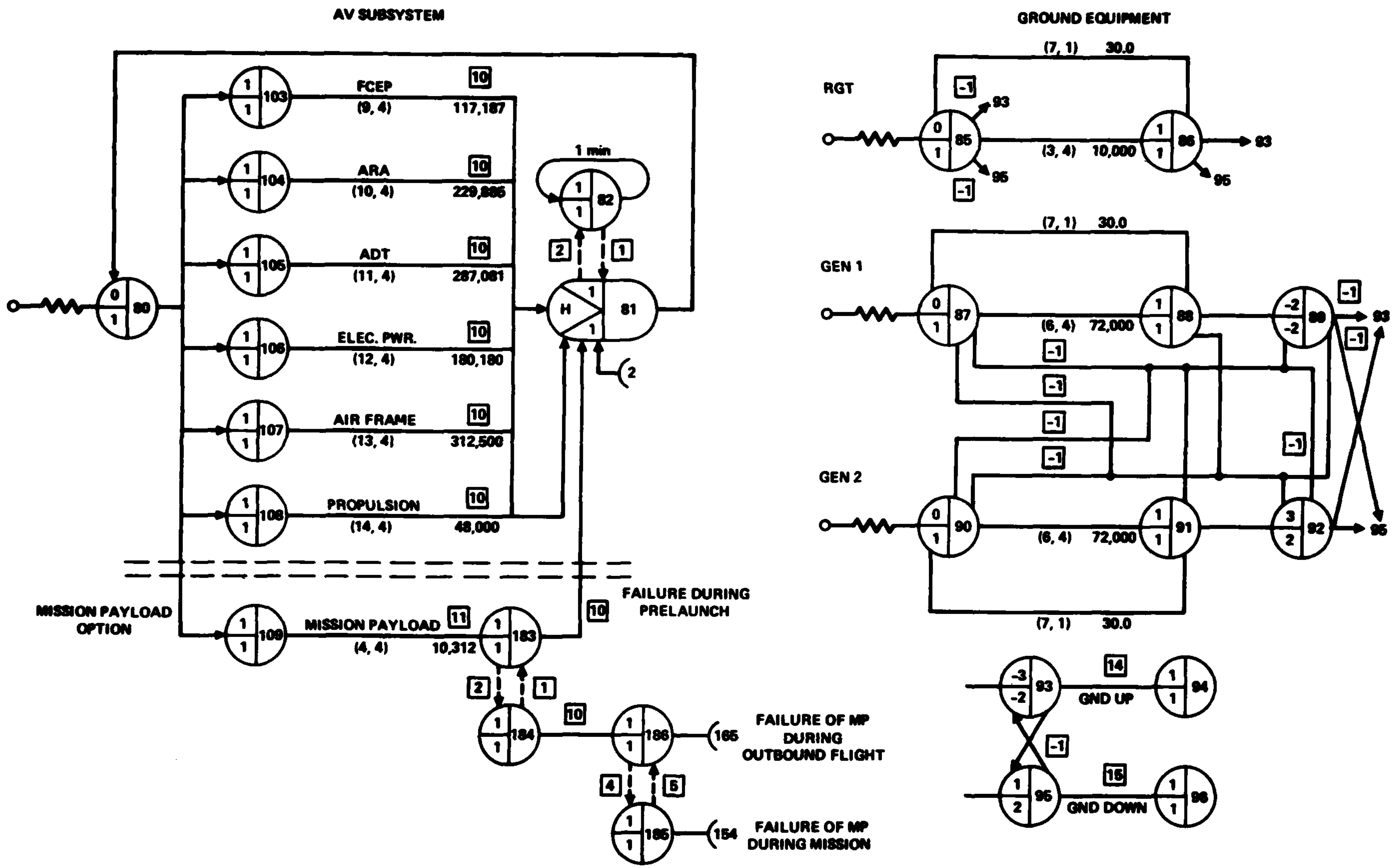

Figure 10.- AV subsystem, ground equipment.

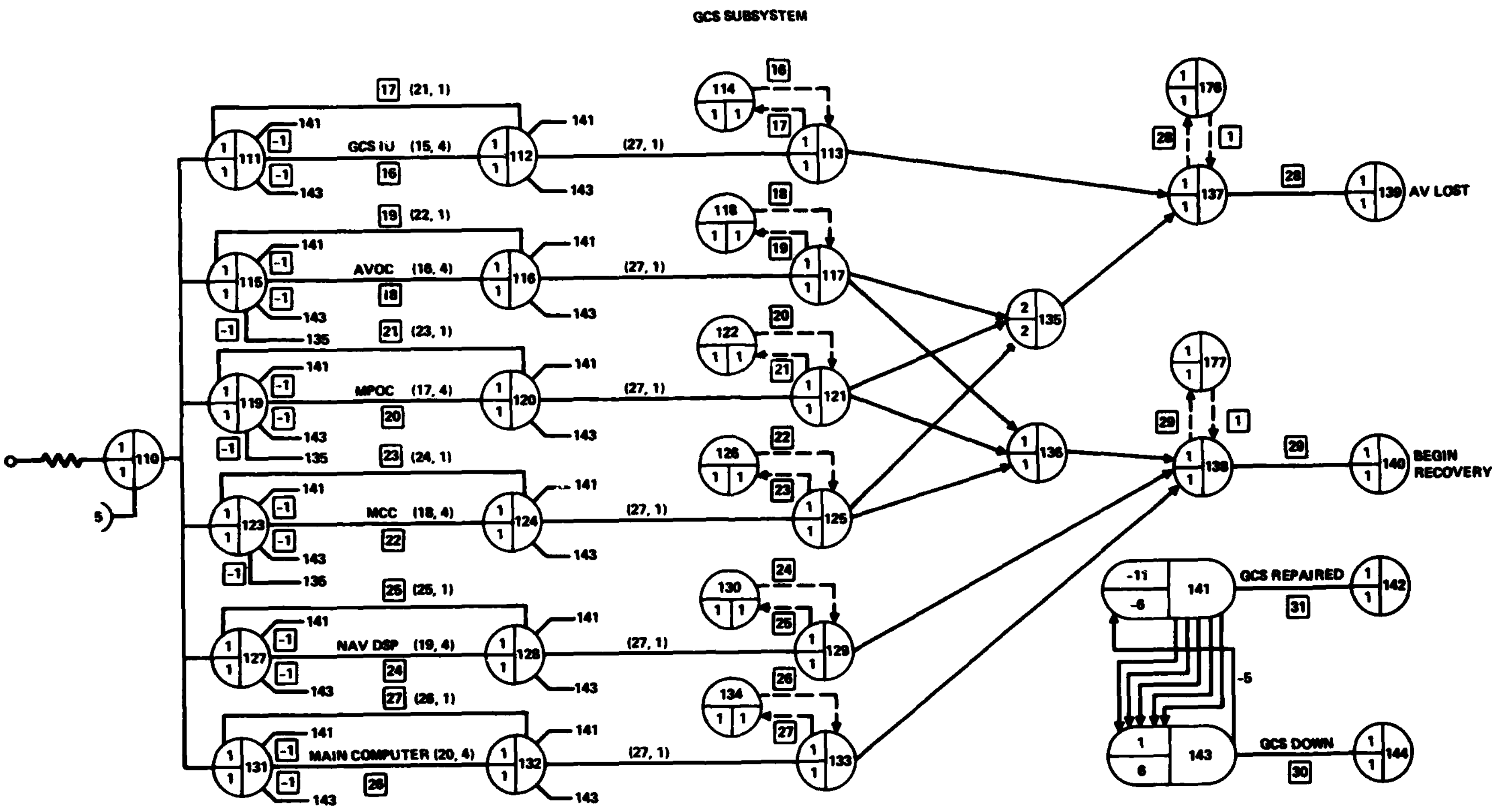

Figure 11.- GCS subsystem, ground equipment.

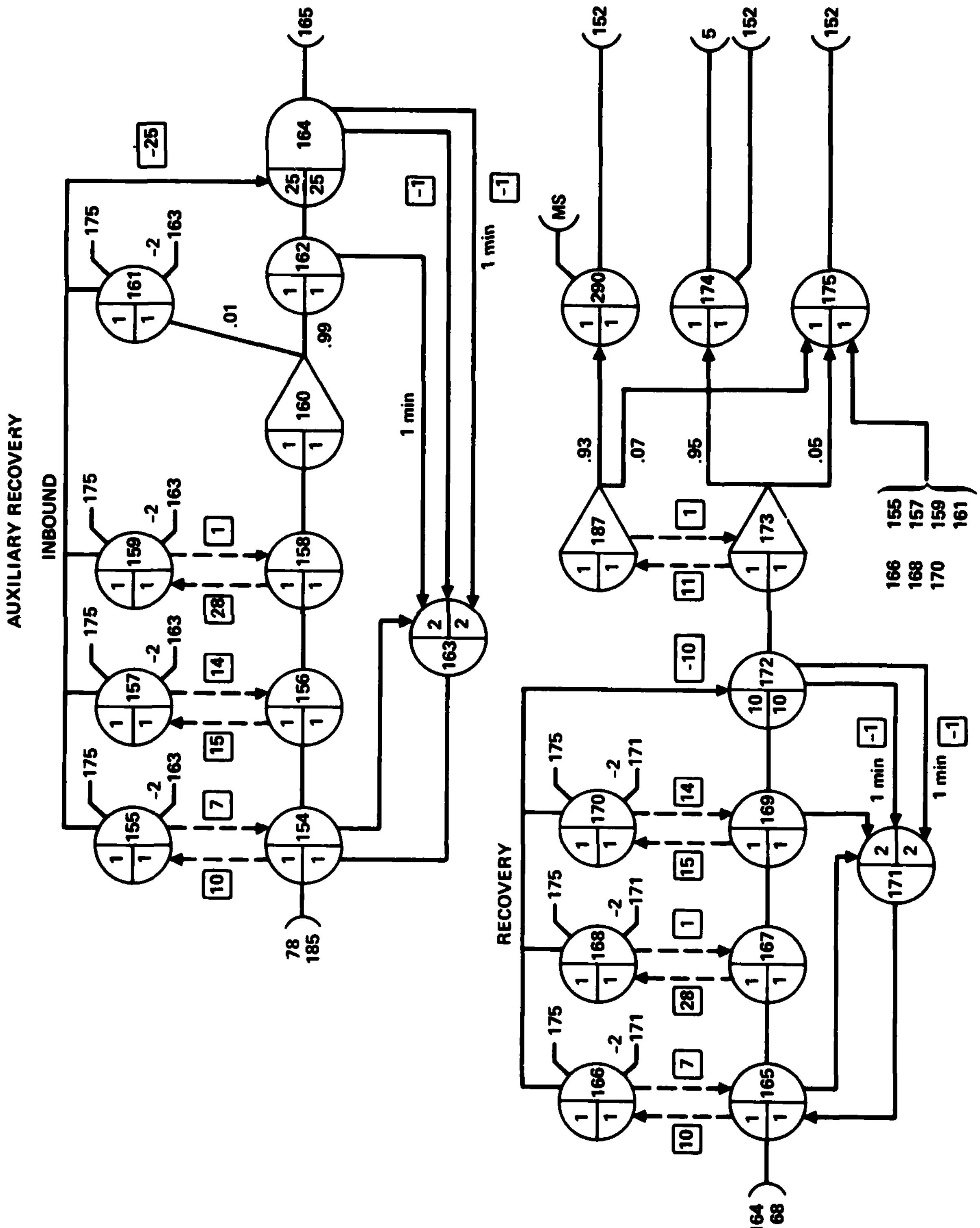

Figure 12.- Auxiliary recovery.

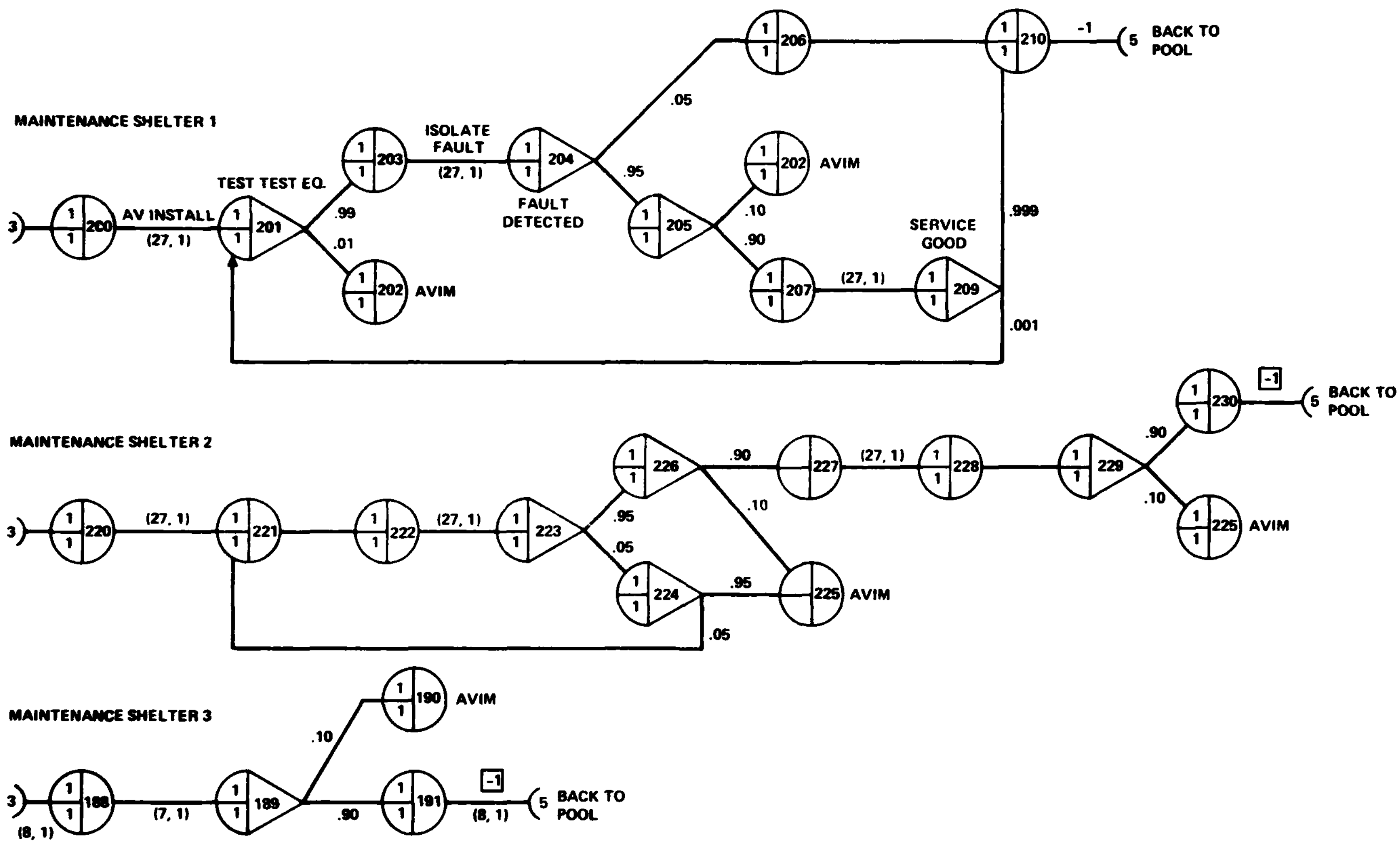

Figure 13. Maintenance shelter plans 1, 2, 3.

APPENDIX B

NODE-ARC DESCRIPTIONS

This section describes the meanings for the nodes and arcs in the node diagrams. The section is categorized by node number with the description of the arcs following.

PRELAUNCH, CLIMBOUT (Figure 6)

Node	Significance
2	Indicates start of simulation, start of preflight/prelaunch check Arc 2-11: begins prelaunch check Arc 2-81: checks the AV for starting new distribution
3	Indicates abort required due to AV failure Arc 3-10: issues abort Arc 3-5: removes inoperative AV from launcher within a 15-min period Distribution 1, parameter 8
4	Indicates new AV from pool placed on launcher Arc 4-6: requires 15-min replacement period Distribution 1, parameter 8 Arc 4-5: removes one AV from ready-pool
5	Indicates number of AV's used: N1 = 5, N2 = 5 (N2 indicates all AV's used; simulation over)
6	Indicates simultaneous readiness of GCS and of AV on launcher Arc 6-2: both GCS and AV ready for prelaunch check
7	Indicates prelaunch check stopped due to ground component failure (GEN & RGT); 15 performed but not 14 Arc 7-178: ground equipment working
8	Indicates ground equipment not working; waiting for repair (14) from arc 93-94 Arc 8-8: pulse cycling on 1-min Distribution 1, parameter 1; wait for repair
178	Indicates whether prelaunch was aborted due to GCS failure Arc 178-9: GCS backup
179	Indicates GCS still down in repair Arc 179-179: 1-min check — when GCS repaired, pulse transfers back to arc 178-9

Node	Significance
9	Indicates junction (receiver node); ready to begin prelaunch Arc 9-10: updater arc to count aborts Arc 9-2: repairs finished, start prelaunch again
10	Indicates number of aborts during prelaunch due to AV, GCS, or GND (nodes 12, 14, 26 respectively); aborts due to no-engine start (node 19); and during a failed launcher (node 21)
11	Indicates prelaunch check of AV systems; if AV not working a 10 from 103-9 occurs, thus replacing 11 by 12
12	Indicates AV not working, 10 occurred in AV subsystem 103-9 Arc 12-15: update 1-min back counter (-2) Arc 12-17: update 5-min front counter (-5) Arc 12-6: shows GCS still functioning Arc 12-3: starts removal and replacement of AV
13	Indicates whether ground equipment (GENs and RGT) is working — if not, 15 occurs from arc 95-96, output of node 13 is replaced by node 14 Arc 13-16: ground equipment working, continue prelaunch check
14	Indicates ground equipment failure (caused by 15 from arc 95-96), stops prelaunch for repairs Arc 14-17: update 5-min front counter (-5) Arc 14-15: update 1-min back counter (-2) Arc 14-7: removal pulse to node 7, where node 7/8 releases pulse when ground equipment is repaired
16	Indicates whether GCS is working — if not, 30 from arc 143-144 replaces output of 16 with output of 26 Arc 16-17: indicates GCS working, updates node 17 and decreases 5 to 4, then 4 to 3, etc. (This is how 5 min are counted. If prelaunch time is changed to 10 min, then replace N1 and N2 of node 17 with 10) Arc 16-15: 1-min loop back occurring 5 times results in 5 min for prelaunch node 15 at 1 (due to 11); at 0, node releases and prelaunch starts again
26	Indicates GCS failure (caused by 30 from arc 143-144); prelaunch stopped for repairs which puts node 26 with 16 Arc 26-17: update 5-min front counter (-5) Arc 26-15: update 1-min back counter (-2) Arc 26-7: GCS failure, waits at 7 until GCS repaired (actually, 7 moves to 178, but model waits at 179, continues check until GCS is ready)

Node	Significance
15	Indicates reset of 1-min counter if prelaunch aborted by 12, 14, 26, or 17 (when released) Arc 15-11: start prelaunch again
17	Indicates the number of 1-min checks that have been made (if prelaunch becomes 10 min, change N1 and N2 to 10) Arc 17-18: prelaunch acceptable, attempt to start engine Arc 17-15: update 1-min counter to stop Indicates another prelaunch check — if another item needs to be checked during prelaunch, follow same format; arc 13-16 includes possibility for failure as represented by dotted lines, and must have repair status like GCS $\boxed{31}$. Also, 1) Update 17 with -5 2) Update 15 with -2 3) Divert to 7 to create failure similar to GCS 4) Place operating up and down between Arc 7-178
18	Indicates engine start, a probablistic node in that the engine may or may not work Arc 18-20: the probability of the engine working .999 defined on arc Arc 18-19: the probability of the engine not working .001 defined on arc
19	Indicates engine did not start, AV failed on launcher Arc 19-3: start abort and replacement of AV
20	Indicates engine working, the command is given for the launch of AV Arc 20-21: launcher failed .001, needs 15-min to repair Arc 20-22: launcher worked, AV in air, .999, mission flight has begun
21	Indicates launcher failed but has been fixed now due to the 15 min along arc 20-21 Arc 21-9: count as abort so that another prelaunch can begin
22	Indicates launcher worked, AV in air and mission flight has begun Arc 22-4: start the 15 min needed to prepare another AV on the launcher Arc 22-23: 1-min time no signal, just sending pulse to climbout
23	Indicates AV is up and working (similar to prelaunch node 11) Arc 23-24: AV has failed somewhere Arc 23-25: Update arc for the 5-min climbout Arc 23-27: AV OK, continue to check other components

Node	Significance
24	Indicates AV failure, AV will crash or an MP failed and will be taken up in 154 Arc 24-29: update 5-min counter (-5) Arc 24-25: update 1-min counter (-2) Arc 24-71: failure of mission flight
25	(see 36) Arc 25-23
27	Indicates ground equipment system check Arc 27-28: failure Arc 27-37: ground equipment OK, continue
28	Indicates ground equipment failure Arc 28-29: update 5-min counter (-5) Arc 28-25: update 1-min counter (-2) Arc 28-71: failure of mission flight, AV lost
29	Indicates the number of 1-min checks that have been made; if necessary to change climbout to 10 min, changes N1 and N2 of mode 29 to 10. Arc 29-30: climbout OK, all systems good for 5 min Arc 29-25: updates 1-min counter (node 25) to stop
37	Indicates loss of AV control through GCS passing arcs 137 to 139, resulting in the loss of an AV Arc 37-45: if via arc 137-139, GCS down Arc 37-58: GCS OK, continue
45	Indicates GCS failure to the point at which control of an AV cannot be maintained, $\boxed{28}$ occurs where flight is stopped, AV lost Arc 45-37: resets node back upon starting a prelaunch Arc 45-29: updates 5-min counter (-5) Arc 45-25: updates 1-min counter (-2) Arc 45-71: stops flight and exits
58	Indicates whether GCS passed arc 138-140 which means GCS cannot perform a flight, but control of AV is still good enough to attempt a recovery Arc 58-68: done by arc 138-140 GCS down/start recovery Arc 58-29: update 5-min counter Arc 58-25: ready to begin next 1-min check; distribution 1, parameter 1
68	Indicates GCS failure, but control of AV is still possible, then $\boxed{29}$ occurs, then exit baseline model and recover Arc 68-58: GCS OK, reset Arc 68-29: update 5-min counter Arc 68-25: update 1-min counter Arc 68-165: start recovery part of flight

Node	Significance
30	Indicates beginning of outbound system check, starting with operation of AV subsystems Arc 30-31: AV subsystem failed, exit via $\boxed{10}$ Arc 30-32: AV subsystems OK, continue Arc 30-36: update 1-min counter to ready

OUTBOUND, MISSION (Figure 7)

Node	Significance
31	Indicates AV subsystem failure; from 103 to 108 and 109 if MP is included in dataset Arc 31-30: flight over, reset Arc 31-39: update 20-min counter Arc 31-71: stop flight, mission flight failure due to AV subsystem Arc 31-36: update 1-min counter to stop
32	Indicates ground-equipment system check Arc 32-33: done by $\boxed{15}$ showing failure Arc 32-75: ground equipment OK, continue
33	Indicates ground equipment failure Arc 33-32: ground equipment fixed via $\boxed{14}$ Arc 33-39: update 20-min counter (-20) Arc 33-71: mission flight failure, AV lost Arc 33-36: update 1-min counter to stop
75	(see 37) Arc 75-76: caused by arc 137-139, GCS down Arc 75-77: GCS OK, continue
76	(see 45) Arc 76-75: resets GCS back to working status upon prelaunch $\boxed{1}$ Arc 76-71: stops flight and exits Arc 76-36: updates 1-min counter to stop Arc 76-39: updates 20-min counter (-20)
77	(see 58) Arc 77-78: done by arc 138-140, GCS down/start recovery Arc 77-34: GCS OK, continue
78	(see 68) Arc 78-77: GCS OK, reset arc to prelaunch Arc 78-39: update 20-min counter Arc 78-36: update 1-min counter Arc 78-154: start recovery part of flight

Node	Significance
34	Indicates environmental check for the possibility of being shot down Arc 34-38: AV survived .999 on arc Arc 34-35: AV shotdown .001 on arc
35	Indicates AV shot down-lost Arc 35-39: update 20-min counter (-20) Arc 35-71: mission flight failure, AV lost Arc 35-36: update 1-min counter to stop
38	Indicates AV survived/split node from probability node Arc 38-36: ready to begin next 1-min check; distribution 1, parameter 1 Arc 38-39: update 20-min counter (1)
36	Indicates start of 1-min counter which sequences the checks Arc 36-30: start check again
39	Indicates the number of 1-min checks that have been made Arc 39-40: outbound flight good, continue 1 min $\boxed{4}$ distribution 1, parameter 1 Arc 39-36: stop 1-min counter, reset (-1) Arc 39-36: stop 1-min counter (-1, 1 min)
40	Indicates beginning of mission system check and check of AV subsystems Arc 40-41: AV subsystem failed, exit via $\boxed{10}$ Arc 40-44: update 1-min counter to ready Arc 40-42: AV subsystems OK, continue
41	Indicates AV subsystem failure; from 103 to 108 and 109 if MP included in dataset Arc 41-40: flight over, reset Arc 41-49: update 120-min counter (two-60's) Arc 41-44: update 1-min counter to stop Arc 41-71: mission flight failure
42	Indicates ground equipment system check Arc 42-43: done by $\boxed{15}$ failure Arc 42-79: ground equipment OK, continue
43	Indicates ground equipment failure Arc 43-42: ground equipment fixed via $\boxed{14}$ Arc 43-49: update 120-min counter (two-60's) Arc 43-44: update 1-min counter to stop Arc 43-71: mission flight failure
44	Indicates start of 1-min counter which sequences the checks Arc 44-40: start check again

Node	Significance
79	(see 37) Arc 79-145: caused by arc 137-139, GCS down Arc 79-146: GCS OK, continue
145	(see 45) Arc 145-79: resets node back upon starting a prelaunch Arc 145-49: updates 120-min counter (two-60's) Arc 145-71: stops mission and exits Arc 145-44: updates 1-min counter (-2)
146	(see 58) Arc 146-147: caused by arc 138-140, GCS down/start recovery Arc 146-46: GCS OK, continue
147	(see 68) Arc 147-146: GCS OK, reset Arc 147-154: start inbound and recovery of AV Arc 147-49: update 120-min counter Arc 147-44: update 1-min counter
46	Indicates environmental check for the possibility of being shot down Arc 46-47: AV shot down (.001 on arc) Arc 46-48: AV survived (.999 on arc)
47	Indicates AV shot down — lost Arc 47-49: update 20-min counter (-120) Arc 47-71: mission flight failure, AV lost Arc 47-44: update 1-min counter (-2) to stop
48	Indicates AV survived/split node from probability node Arc 48-49: update 120-min counter (1) Arc 48-44: ready to begin next 1 min
49	Indicates the number of 1-min checks made during the mission Arc 49-50: mission good, continue with inbound 1 min $\boxed{5}$ distribution 1, parameter 1 Arc 49-49: stop 1-min counter reset (-1) Arc 49-44: stop 1-min counter reset (-1, 1 min)
50	Indicates how many times the RPV passed the mission (statistics node) Arc 50-53: send pulse on
51/52	Indicates the number of "sets of three" of completed missions (both nodes do the same job)

INBOUND, RECOVERY (Figure 8)

Node	Significance
53	Indicates beginning of inbound systems check, starting with operation of AV subsystems
	Arc 53-54: AV subsystem failed, exit via $\boxed{10}$
	Arc 53-56: AV subsystem OK, continue
	Arc 53-57: update 1-min counter
54	Indicates subsystem failure from 103 to 108 and 109 if MP is included in dataset
	Arc 54-53: flight over, reset
	Arc 54-62: update 25-min counter (-25)
	Arc 54-57: update 1-min counter to stop
	Arc 54-71: stop flight, mission flight failure due to AV subsystem
56	Indicates ground equipment system check
	Arc 56-55: done by $\boxed{15}$ failure
	Arc 56-148: ground equipment OK, continue
55	Indicates equipment failure
	Arc 55-56: ground equipment fixed via $\boxed{14}$
	Arc 55-62: update 25-min counter (-25)
	Arc 55-57: update 1-min counter to stop
	Arc 55-71: mission flight failure, AV lost
148	Indicates loss of AV control through GCS passing arcs 137-139, resulting in the loss of an AV
	Arc 148-149: GCS down done by arc 137-139
	Arc 149-59: GCS OK, continue
149	Indicates GCS failure to the point at which control of an AV cannot be maintained $\boxed{28}$ occurs where flight is stopped, AV lost
	Arc 149-148: resets node back upon starting a prelaunch
	Arc 149-62: updates 25-min counter (-25)
	Arc 149-57: updates 1-min counter to stop
	Arc 149-71: stops flight, AV lost, and exit
59	Indicates environmental check for the possibility of being shot down
	Arc 59-60: AV shot down (.001 on arc)
	Arc 59-61: AV survived (.999 on arc)
60	Indicates AV shot down, lost
	Arc 60-62: update 25-min counter
	Arc 60-71: mission flight failure, AV lost
	Arc 60-57: update 1-min counter to stop

Node	Significance
61	Indicates AV survived/split node from probability node Arc 61-62: update 20-min counter Arc 61-57: ready to begin next 1-min check; distribution 1, parameter 1
57	Indicates start of 1-min counter which sequences the checks Arc 57-53: start check again
62	Indicates the number of 1-min checks that will be made. (If necessary, inbound can be changed, for example, from 25 to 30, simply by replacing N1 and N2 with 30 in node 62) Arc 62-63: inbound flight good, continue 1 min; distribution 1, parameter 1 Arc 62-57: stop 1-min counter reset (-1) Arc 62-57: stop 1-min counter reset (-1, 1 min)
63	Indicates beginning of recovery, checking of AV subsystems Arc 63-64: AV subsystem failed, exit via $\boxed{10}$ Arc 63-66: AV subsystem OK, continue Arc 63-67: update 1-min counter to ready
64	Indicates AV subsystem failure from 103 to 108 and 109 if MP included in dataset Arc 64-63: flight over, reset Arc 64-69: update 10-min recovery counter Arc 64-67: update 1-min recovery counter to stop Arc 64-71: mission flight failure
66	Indicates ground equipment system check Arc 66-65: done by $\boxed{15}$ failure Arc 66-150: ground equipment OK, continue
65	Indicates ground equipment failure Arc 65-66: ground equipment fixed via $\boxed{14}$ Arc 65-71: mission flight failure Arc 65-69: update 10-min counter (-10) Arc 65-67: update 1-min counter to stop
151	Indicates GCS failure to the point at which control of AV cannot be maintained $\boxed{28}$ occurs where flight is stopped, AV lost Arc 151-150: resets node back upon starting a prelaunch $\boxed{1}$ Arc 151-67: updates 1-min counter to stop Arc 151-69: updates 10-min counter (-10) Arc 151-71: stops flight, AV lost, and exit
67	Indicates start of 1-min counter which sequences the checks Arc 67-63: starts check again

Node	Significance
69	Indicates the number of 1-min checks during the recovery that have been made Arc 69-70: recovery good (till net), continue with probability of net working Arc 69-69: stop 1-min counter reset (-1) Arc 69-67: stop 1-min counter reset (-1, 1 min)
70	Indicates the probability that recovery net works Arc 70-72: net work good, AV recovered (.99) Arc 70-71: net failed, AV lost (.01)

RECOVERY, TIMER (Figure 9)

Node	Significance
71	Indicates mission flight failure; AV lost; however, if MP failed, then mission is not considered a failure
289	Indicates whether failure occurred in MP Arc 289-288: if failure in MP, hold Arc 289-152: failure not in MP; AV lost, reset
288	Indicates pulse stopped; MP failed but AV in recovery mode; pulse reestablished from subrecovery mode Arc 288-289: reset
72	Indicates mission flight successful; no problems disrupted the baseline program; mission counts as one good 3-hr sortie Arc 72-73: update 3-sortie counter Arc 72-152: update GCS available Arc 72-74: put AV back in pool
73	Indicates the number of days in which three 3-hr sorties were completed successfully Arc 73-102: $\boxed{32}$ stop 12-hr clock; three mission flights have been completed within the time period
74	Indicates AV replacement into pool Arc 74-5: where 5 is pool, -1 to add to counter
152	Indicates GCS checked for readiness Arc 152-153: stop and hold until GCS is fixed Arc 152-6: GCS available, start prelaunch again
153	Indicates system holding until GCS is ready Arc 153-152: GCS is ready, return Arc 152-152: 1-min loop. Checks status of GCS every 1 min (helps prevent infinite loops)

Node	Significance
101	Indicates start of 12-hr clock at beginning of simulation; if clock runs out before completion of three good sorties (Arc 73-102), simulation is terminated (end of daylight hrs) Arc 101-102: 12 hr have passed
102	Indicates pulse received for completion of three mission flights or for completion of 12-hr period Arc 102-180: three sorties completed first Arc 102-181: 12 hrs have passed
180	Indicates three mission flights were completed, 12-hr clock starts again and records in N229 Arc 180-101: starts 12-hr clock for next day, model starts prelaunch automatically with Arc 152-6 Arc 180-299: decrease 299 by one
299	Indicates maximum of 10 successful days, then stops simulation run Arc 299: sink node
181	Indicates three sorties were not completed within 12 hrs; 12 hr arrived at 102 first and diverted to 181 Arc 181-182: send pulse to stop simulation
182	Indicates 12 hrs over before three mission flights, collect statistics Arc 182: sink node

AV SUBSYSTEM (Figure 10)

80	Indicates beginning of simulation; starts all components of AV Arc 80-103: starts FCEP distribution Arc 80-104: starts ARA distribution Arc 80-105: starts ADT distribution Arc 80-106: starts electric power distribution Arc 80-107: starts airframe distribution Arc 80-108: starts prop distribution Arc 80-109: starts mission payload distribution
103	Indicates beginning of distribution for FCEP Arc 103-81: distribution 4, parameter 9, number 10
104	Indicates beginning of distribution for ARA Arc 104-81: distribution 4, parameter 10, number 10
105	Indicates beginning of distribution for ADT Arc 105-81: distribution 4, parameter 11, number 10

Node	Significance
106	Indicates beginning of distribution for electric power Arc 106-81: distribution 4, parameter 12, number 10
107	Indicates beginning of distribution for the airframe Arc 107-81: distribution 4, parameter 13, number 10
108	Indicates beginning of distribution for the prop Arc 108-81: distribution 4, parameter 14, number 10
109	Indicates beginning of distribution for the MP Arc 109-183: distribution 4, parameter 4, number 11
183	Indicates failure of mission payload Arc 183-81: failure occurred in mission payload during prelaunch check Arc 183-184: node exchange done after prelaunch $\boxed{2}$
81	Indicates failure in an AV subsystem (from 103 to 108 and 183) or distributions stop and restart; by 2 (the H denotes the halt command specified in GRASP in which one pulse is received, and the others are ignored) Arc 81-82: hold pulse until prelaunch is ready again Arc 81-80: start a new set of AV distribution for an AV on the launcher
82	Indicates pulse is postponed until prelaunch is ready Arc 82-82: return pulse Arc 82-81: return pulse to node 81 to start A
184	Indicates failure of mission payload after prelaunch before mission return of AV Arc 184-183: reset node back before prelaunch Arc 184-186: failure occurred, start recovery
185	Indicates failure of mission payload during mission return of AV via an inbound flight Arc 185-186: reset back with $\boxed{5}$ Arc 185-154: send pulse to auxiliary recovery — inbound
186	Indicates failure of mission payload during climbout and outbound flight Arc 186-165: send pulse to auxiliary recovery Arc 186-185: divert pulse to auxiliary recovery on inbound if mission payload fails

GROUND EQUIPMENT (Figure 10)

Node	Significance
85	Indicates beginning of simulation Arc 85-86: starts RGT failure distribution; distribution 4, parameter 3 Arc 85-93: updates ground equipment status Arc 85-95: update ground equipment status
86	Indicates failure of RGT Arc 86-93: update ground equipment status Arc 86-95: update ground equipment status Arc 86-85: repair of RGT; distribution 1, parameter 7
87	Indicates beginning of simulation Arc 87-88: starts generator failure distribution; distribution 4, parameter 6 Arc 87-89: updates ground equipment status Arc 87-92: updates ground equipment status
88	Indicates failure of generator 1 Arc 88-87: repair of generator 1; distribution 1, parameter 7 Arc 88-89: update ground equipment status Arc 88-92: update ground equipment status
89	Indicates whether one of two generators is working Arc 89-93: update arc Arc 89-95: update arc Arc 89-92: update arc
90	Indicates beginning of simulation Arc 90-91: starts generator failure distribution Arc 90-89: update ground equipment status Arc 90-92: update ground equipment status
91	Indicates failure of generator 2 Arc 91-90: repair of generator 2; distribution 1, parameter 7 Arc 91-92: update ground equipment status Arc 91-89: update ground equipment status
92	Indicates whether or not both generators are working Arc 92-95: update arc Arc 92-93: update arc Arc 92-89: update arc
93	Indicates GCS status (update node) Arc 93-95: update arc Arc 93-94: arc for ground equipment status up $\boxed{14}$
94	Indicates ground equipment working

Node	Significance
95	Indicates GCS status (update node) Arc 95-93: update arc Arc 95-96: arc for ground equipment status down $\boxed{15}$
96	Indicates ground equipment not working

GROUND CONTROL STATION (Figure 11)

Node	Significance
110	Indicates beginning of GCS subsystem distributions Arc 110-111: starts the GCSIU distribution Arc 110-115: starts the AVOC console distribution Arc 110-119: starts the MP console distribution Arc 110-123: starts the MC console distribution Arc 110-127: starts the NDU distribution Arc 110-131: starts the main computer distribution Arc 110-5: subtracts one AV from the AV-ready pool when one AV is on launcher at start of simulation — this is easier than any other method
111	Indicates beginning of GCSIU distribution Arc 111-112: GCSIU parameter set 15, distribution 4 Arc 111-141: updater arc for GCS up (141-142) Arc 111-143: updater arc for GCS down (143-144)
112	Indicates GCSIU failure Arc 112-111: start repair; parameter 21, distribution 1, number $\boxed{17}$ Arc 112-141: updater arc for GCS repaired Arc 112-143: updater arc for GCS down Arc 112-113: timed check to see if GCSIU can be repaired before fail is scheduled; distribution 1, parameter set 27
113	Indicates available time for on-site repair has passed and observed vehicle must be scheduled for repair — GCSIU Arc 113-114: repair did not take place within check time schedule failure Arc 113-114: divert pulse to stop $\boxed{17}$ Repair has taken place within the check time
114	Indicates pulse stopped, failure of GCSIU Arc 114-113: reset back $\boxed{16}$
115	Indicates beginning of AVOC distribution Arc 115-116: AVOC parameter set 16, distribution 4 Arc 115-141: updater arc for GCS up (141-142) Arc 115-143: updater arc for GCS down (143-144) Arc 115-135: updater for two console failure

Node	Significance
116	Indicates AVOC failure Arc 116-115: start repair parameter set 22, distribution 1 Arc 116-141: updater arc for GCS repaired Arc 116-142: updater arc for GCS down Arc 116-117: timed check to see if AVOC can be repaired before failing; parameter set 27, distribution 1
117	Indicates available time for on-site repair has passed and observed vehicle must be scheduled for repair — AVOC Arc 117-135: repair did not take place within check time; schedule failure Arc 117-136: repair did not take place within check time; schedule failure Arc 117-118: divert pulse to stop 19
118	Indicates pulse stopped due to failure of AVOC Arc 118-117: reset back 18
119	Indicates beginning of MPC distribution Arc 119-120: MPC parameter set 17, distribution 4 Arc 119-141: updater arc for GCS up (141-142) Arc 119-143: updater arc for GCS down (143-144) Arc 119-135: updater for two console failure
120	Indicates MPC failure Arc 120-119: start repair parameter set 23, distribution 1 Arc 120-141: updater arc for GCS repaired Arc 120-142: updater arc for GCS down Arc 120-121: timed check to see if MPC can be repaired before failing parameter set 27, distribution 1
121	Indicates available time for on-site repair has passed and observed vehicle must be scheduled for repair — MPC Arc 121-135: repair did not take place within check time failure scheduled Arc 121-136: repair did not take place within check time failure scheduled Arc 121-122: divert pulse to stop 21
122	Indicates pulse stopped for failure of MPC Arc 122-121: reset back 20
123	Indicates beginning of MCC distribution Arc 123-124: MPC parameter set 18, distribution 4 Arc 123-141: updater arc for GCS up (141-142) Arc 123-143: updater arc for GCS down (143-144) Arc 123-135: updater for two console failures

Node	Significance
124	Indicates MCC failure Arc 124-123: start repair parameter set 24, distribution 1 Arc 124-141: updater arc for GCS repaired Arc 124-143: updater arc for GCS down Arc 124-125: timed check to see if MCC can be repaired before failing parameter set 27, distribution 1
125	Indicates time over — MCC Arc 125-135: repair did not take place within check time failure schedule Arc 125-136: repair did not take place within check time failure schedule Arc 125-126: divert pulse to stop $\boxed{23}$
126	Indicates pulse stopped for failure of MCC Arc 126-125: reset back $\boxed{22}$
127	Indicates beginning of NDU distribution Arc 127-129: NDU parameter set 19, distribution 4 Arc 127-141: updater arc for GCS up (141-142) Arc 127-143: updater arc for GCS down (143-144)
128	Indicates NDU failure Arc 128-127: start repair parameter set 25, distribution 1 Arc 128-141: updater arc for GCS repaired Arc 128-143: updater arc for GCS down Arc 128-129: timed check to see if NDU can be repaired before failing; parameter set 27, distribution 1
129	Indicates time over — NDU Arc 129-138: repair did not take place within check time recovery scheduled Arc 129-130: divert pulse to stop $\boxed{25}$
130	Indicates pulse stopped for NDU failure Arc 130-129: reset back $\boxed{24}$
131	Indicates beginning of main computer distribution Arc 131-132: main computer parameter set 20, distribution 4 Arc 131-141: updater arc for GCS up (141-142) Arc 131-143: updater arc for GCS down (143-144)
132	Indicates main computer failure Arc 132-131: start repair; parameter set 26, distribution 1 Arc 132-141: updater arc for GCS repaired Arc 132-143: updater arc for GCS down Arc 132-133: timed check to see if main computer can be repaired before failing; distribution 1, parameter set 27

Node	Significance
133	Indicates time over — main computer Arc 133-138: repair did not take place within check time recovery scheduled Arc 133-134: divert pulse to stop $\boxed{27}$
134	Indicates pulse stopped due to failure of main computer Arc 134-133: reset back $\boxed{26}$
135*	Indicates failure of two consoles Arc 135-137: failure of GCS — if AV is in the air, it's lost
136*	Indicates failure of one console Arc 136-138: start recovery operations
137	Indicates GCS failure, loss of AV Arc 137-139: failure of GCS scheduled a $\boxed{28}$ for the main model Arc 137-176: guard — protect from having two pulses issued along arc 137-139 for a mission flight
139	Indicates loss of AV
176	Indicates pulse stopped; only one pulse needed Arc 176-137: reset by $\boxed{1}$
138	Indicates failure of GCS, AV returned for recovery Arc 138-140: failure of GCS schedule a $\boxed{29}$ for the main model
140	Indicates beginning of recovery
177	Indicates pulse stopped — only one pulse needed
141	Indicates GCS repaired Arc 141-142: schedule $\boxed{31}$ for main model Arc 141-143: (5) GCS repaired, update
142	Indicates GCS repaired
143	Indicates GCS not working Arc 143-144: GCS down, schedule $\boxed{30}$ for main model Arc 143-141: GCS down, update
144	Indicates GCS not working

*The three-console model here should be redesigned so that three distributions (or as many as necessary) could be altered to indicate loss of AV control to the extent that (1) the mission would be aborted and the AV recovered or (2) recovery would be impossible and the AV lost.

AUXILIARY RECOVERY (Figure 12)

Node	Significance
154	Indicates beginning of auxiliary inbound system check, starting with all AV subsystems Arc 154-155: AV subsystem failed, exit via $\boxed{10}$ Arc 154-156: AV subsystem continue Arc 154-163: update 1-min counter
155	Indicates AV subsystem failure from 103 to 108 and 109 if MP is included in dataset Arc 155-154: flight over, reset Arc 155-164: updater for 25-min counter Arc 155-175: mission flight failure, AV lost Arc 155-163: updater for 1-min counter
156	Indicates ground equipment system check Arc 156-157: done $\boxed{15}$ failure Arc 156-158: ground equipment OK, continue
157	Indicates ground equipment failure Arc 157-156: ground equipment fixed via $\boxed{14}$ Arc 157-164: updater for 25-min counter Arc 157-175: mission flight failure, AV lost Arc 157-163: updater for 1-min counter
158	Indicates loss of AV control through arc 137-139, resulting in loss of AV Arc 158-159: AV lost Arc 137-139: GCS inoperative Arc 158-160: GCS operating, continue mission
159	Indicates GCS failure to the point at which control of an AV cannot be maintained $\boxed{28}$ occurs where flight is stopped and AV lost Arc 159-158: reset node back upon starting a prelaunch Arc 159-175: stops flight, AV lost, and exit Arc 159-164: updates 25-min counter Arc 159-163: updates 1-min counter
160	Indicates environmental check for the possibility of being shot down Arc 160-162: AV survived (.999 on arc) Arc 160-161: AV shot down (.001 on arc)
162	Indicates AV survived/split node from probability node Arc 162-164: update 20-min counter Arc 162-163: ready to begin next 1-min check; distribution 1, parameter set 1

Node	Significance
161	Indicates AV shot down — lost Arc 161-164: update 25-min counter Arc 161-163: update 1-min counter Arc 161-175: mission flight failure, AV lost
163	Indicates start of 1-min counter which sequences the checks Arc 163-154: start check again
164	Indicates the number of 1-min checks that have been made. Arc 164-163: stop 1-min counter, reset (-1) Arc 164-163: stop 1-min counter, reset (-1, 1 min) Arc 164-165: inbound flight good, continue
165	Indicates beginning of recovery, checking of AV subsystem Arc 165-166: AV subsystem failed, exit via $\boxed{10}$ Arc 165-161: update 1-min counter to ready Arc 165-167: AV subsystem OK, continue
166	Indicates AV subsystem failure from 103 to 108 and 109 if MP included in dataset Arc 166-165: flight over, reset Arc 166-172: update 10-min recovery counter Arc 166-171: update 1-min recovery counter to stop Arc 166-175: mission flight failure
167	Indicates GCS failure to the point at which control of an AV cannot be maintained $\boxed{28}$ occurs Arc 167-168: resets node back upon starting a prelaunch $\boxed{1}$ Arc 167-169: GCS OK, continue
168	Indicates GCS failure, AV lost Arc 168-172: update 10-min recovery counter Arc 168-171: update 1-min counter Arc 168-175: mission flight failure, AV lost
169	Indicates ground equipment system check Arc 169-170: done by $\boxed{15}$ failure Arc 169-172: ground equipment working, continue
170	Indicates ground equipment failure Arc 170-169: ground equipment fixed via $\boxed{14}$ Arc 170-172: update 10-min counter Arc 170-171: update 1-min counter to stop
171	Indicates start of 1-min counter which sequences the system checks Arc 171-165: starts check again

Node	Significance
172	Indicates the number of 1-min checks made during the recovery Arc 172-173: recovery good (until net), continue with probability of net Arc 172-171: stop 1-min counter, rest (-1) Arc 172-171: stop 1-min counter, reset (-1, 1 min)
173	Indicates probability that recovery net works Arc 173-174: .95 recovery good Arc 173-175: .05 recovery bad Arc 173-187: node exchange (if MP is bad, probability is lower 11)
187	Indicates probability that recovery net works without MP for guidance Arc 187-190: recovery good .93 Arc 187-175: recovery bad
290	Indicates recovery good, MP failed Arc 290: MS send AV to MS to be repaired Arc 290-152: start new mission flight
174	Indicates recovery good Arc 174-5: AV OK, return to ready pool Arc 174-152: start new mission flight
175	Indicates recovery unsuccessful, AV lost Arc 175-152: start new mission flight

MS1 100% DIAGNOSTICS (Figure 13)

200	Indicates initialization of maintenance shelter 1 Arc 200-201: distribution 1, parameter set 27, installation time
201	Indicates test of test equipment Arc 201-103: test good .99 Arc 201-202: test not good .01, keys in AVIM
202	AVIM
203	Indicates time for fault isolation to work Arc 203-204: parameter set 27, distribution 1, fault isolation
204	Indicates probability of fault being detected Arc 204-206: fault not detected .05 Arc 204-205: fault detected .95
205	Indicates probability of repairing the fault with an LRU Arc 205-202: cannot be repaired at AVUM (.10) Arc 205-207: repaired at AVUM .90

Node	Significance
206	Indicates that repair may need to take place in GSE, LA, REC, GCS, or RGT Arc 206-210: transfer of pulse
207	Indicates time to replace LRU Arc 207-209: distribution 1, parameter set 27
209	Indicates service check Arc 209-210: service good .999 Arc 209-201: service not good, start again .001
210	Indicates service good, send AV back to AV ready pool Arc 210-5: AV to ready pool

MS2 70% CHARACTERISTICS (Figure 13)

Node	Significance
220	Indicates initialization of maintenance shelter 2 Arc 220-221: distribution 1, parameter set 27
221	Indicates idle mode Arc 221-222: transfer pulse
222	Indicates fault isolation time Arc 222-223: distribution 1, parameter set 27
223	Indicates test confirmed from GCS Arc 223-224: test not confirmed .05 Arc 223-226: test confirmed .95
224	Indicates check of testing arrangement Arc 224-225: test arrangement good .95 Arc 224-221: test arrangement bad, start again
225	Send to AVIM
226	Indicates isolation to LRU Arc 226-227: confirmed .90 Arc 226-225: not possible .10
227	Indicates AV sent to repair Arc 227-228: repair time, distribution 1, parameter set 27
228	Indicates end of repair Arc 228-229: send pulse for service check

Node	Significance
229	Indicates service check Arc 229-225: no good, send to AVIM .10 Arc 229-230: service good .90
230	Indicates service good, send AV back to ready pool Arc 230-5: AV to ready pool

MS3 CONTRACT SPECIFICATIONS (Figure 13)

3-188	Indicates installation time; distribution 1, parameter set 1
188	Indicates test for faults Arc 188-189: distribution 1, parameter set 7
189	Indicates probability of problem being fixed Arc 189-190: .10, sent to AVIM Arc 180-191: .90, send to repair
190	AVIM
191	Indicates repair time — send back to ready pool Arc 191-5: parameter 8 $\boxed{-1}$, distribution 1

APPENDIX C

PARAMETER SET

This section describes the numbers used for the distributions. The distributions use a mean time for failure rate determination. Minimum and maximum time-rates are associated with distributions to provide a means for containment of times.

Distribution	Significance
1	Constant 1-min timer; used mostly for 1-min system checks in main program
2	Constant 720-min (12-hr) timer; used to time 1 day's activities Arc 101-102
3	Exponential distribution on RGT 10000.0 mean time in minutes 0.0 minimum time in minutes 99999999.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
4	Mission payload 10,312 mean time in minutes 0.0 minimum time in minutes 99999999.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
5	Old distribution — not used
6	Generators 720,000 mean time in minutes 0.0 minimum time in minutes 99999999.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
7	Constant 30-min timer
8	Constant 15-min timer
9	FCEP 117,187.5 mean time in minutes 0.0 minimum time in minutes 190.0 maximum time in minutes 1.0 puts ERLANG-K into exponential

Distribution	Significance
10	ARA 229885 mean time in minutes 0.0 minimum time in minutes 190.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
11	ADT 287081.34 mean time in minutes 0.0 minimum time in minutes 190.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
12	Electrical power 180180.18 mean time in minutes 0.0 minimum time in minutes 190.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
13	Air frame 312500.00 mean time in minutes 0.0 minimum time in minutes 190.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
14	Propulsion assembly 48000.0 mean time in minutes 0.0 minimum time in minutes 190.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
15	GCS IU 48000.0 mean time in minutes 0.0 minimum time in minutes 99999999.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
16	AVO console 22779.043 mean time in minutes 0.0 minimum time in minutes 99999999.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
17	MPO console 63492.0635 mean time in minutes 0.0 minimum time in minutes 99999999.0 maximum time in minutes 1.0 puts ERLANG-K into exponential

Distribution	Significance
18	MC console 57416.2679 mean time in minutes 0.0 minimum time in minutes 99999999.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
19	NDU console 209790.210 mean time in minutes 0.0 minimum time in minutes 99999999.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
20	GCS main computer 157480.0 mean time in minutes 0.0 minimum time in minutes 99999999.0 maximum time in minutes 1.0 puts ERLANG-K into exponential
21	GCS IU 15.00 constant repair time
22	AVO console 15.00 constant repair time
23	MPO console 15.00 constant repair time
24	MC console 15.00 constant repair time
25	NDU console 15.00 constant repair time
26	GCS main computer 15.00 constant repair time
27	Check time for GCS components 10.00 constant repair time

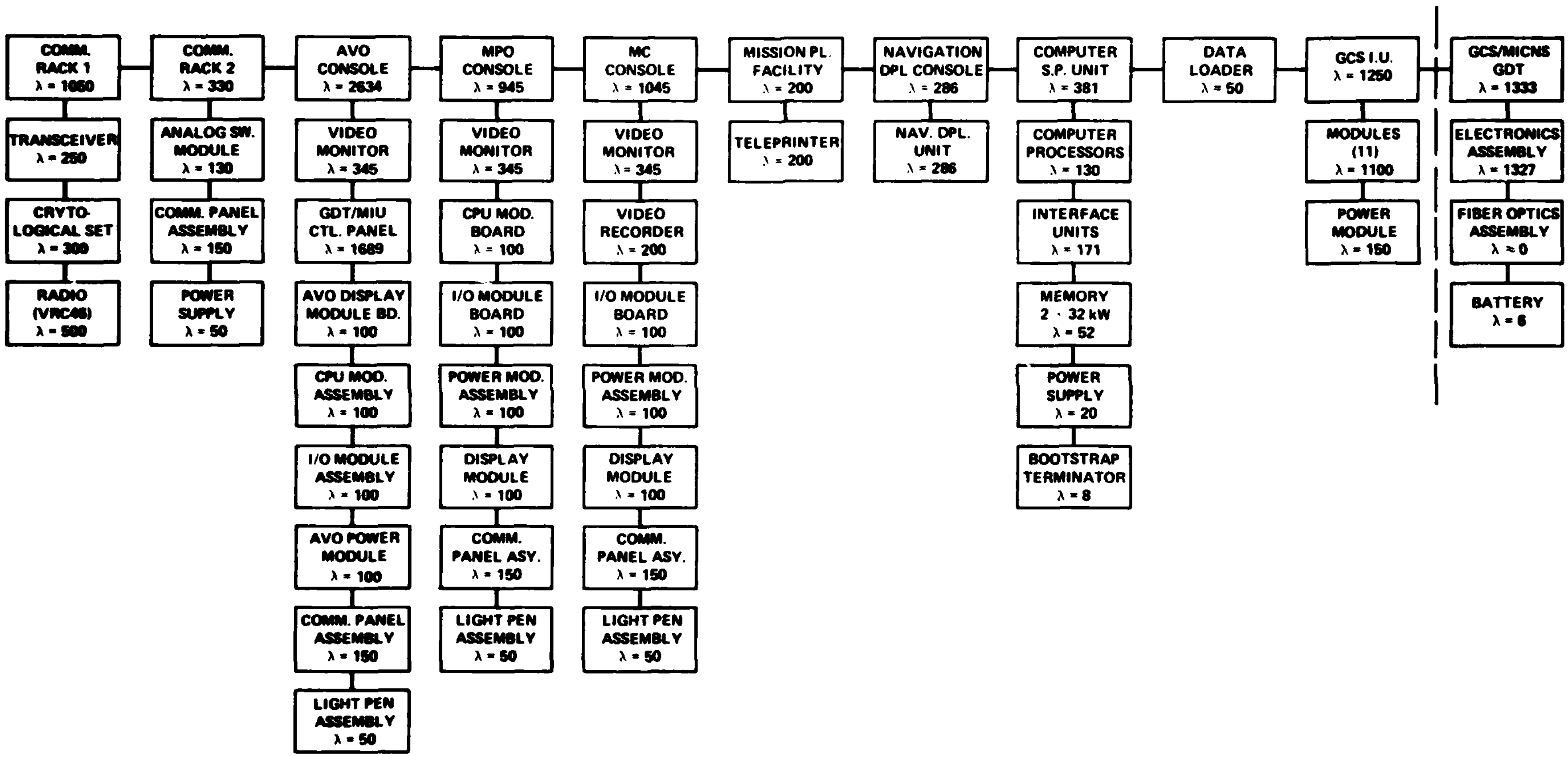

Figure 14.- GCS reliability block diagram.

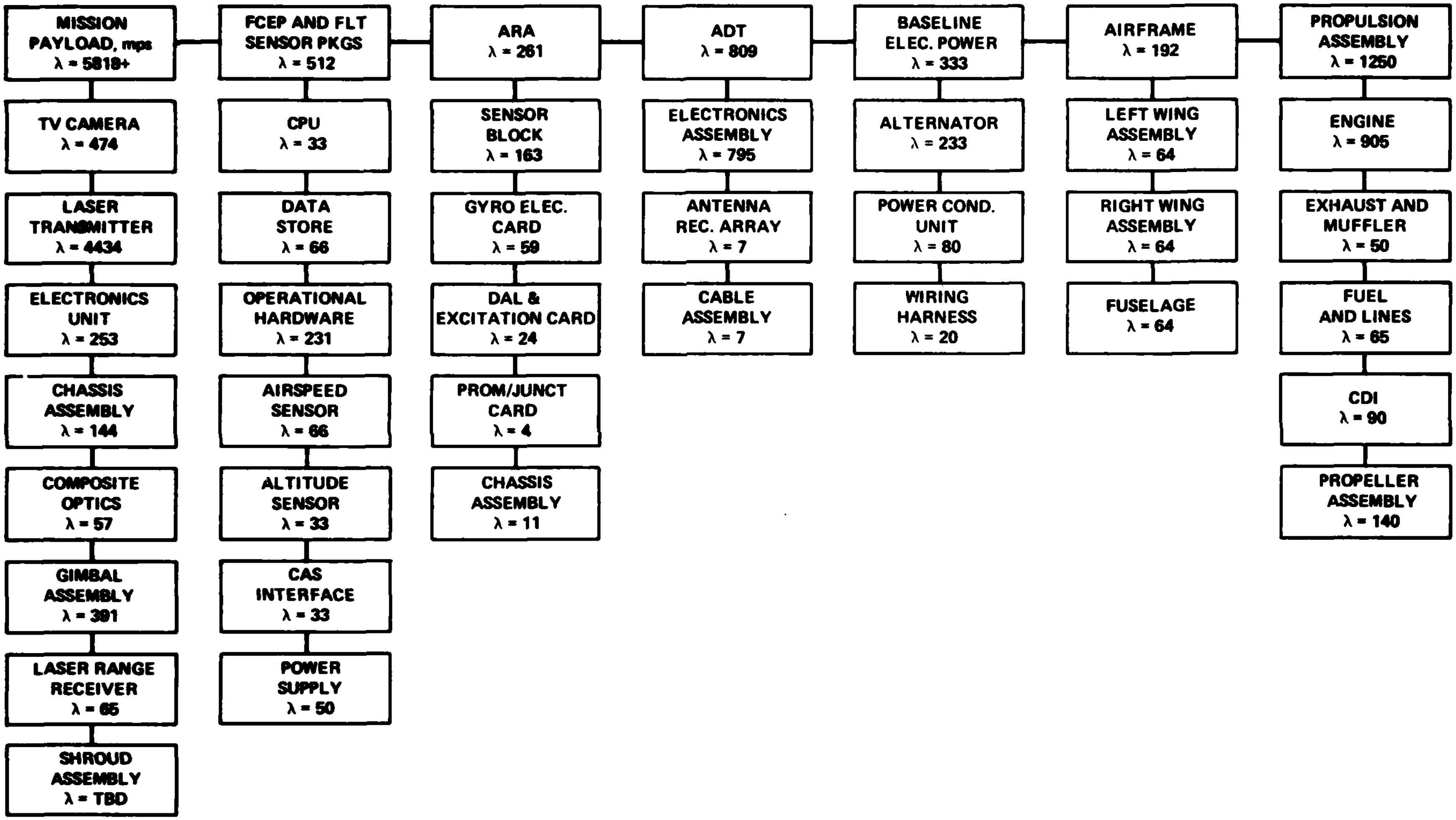

Figure 15.- RPV air vehicle subsystem reliability block diagram.

APPENDIX D

ACTIVITY NUMBERS

Activity numbers are assigned to denote different stages in the simulation. This section describes these stages and which arcs are used.

1	Prelaunch check is about to begin Arc 2-11
2	Prelaunch good/engine start and launch next Arc 17-18
4	AV has passed outbound ready to begin mission Arc 39-40
5	AV has passed mission, mission successful
7	AV has completed recovery approach, flight over
10	AV subsystem component failure
11	Mission payload failure
14	Ground equipment working
15	Ground equipment not working
16	Failure of GCS IU
17	Reapir of GCS IU
18	Failure of AVO console
19	Repair of AVO console
20	Failure of MPO console
21	Repair of MPO console
22	Failure of MC console
23	Repair of MC console
24	Failure of NAV DPL unit

25	Repair of NAV DPL unit
26	Failure of GCS main computer
27	Repair of GCS main computer
30	GCS not working
31	GCS repaired
28	GCS failure — AV lost
29	GCS failure — AV in recovery/inbound (depends on AV location)
32	Successful day completed 3-3 hr sorties within 12 hours
33	Unsuccessful day 12-hr timer finished

ACTIVITY NUMBERS

1 1[illegible] 11 [illegible] 75 [illegible]
-115[illegible]7173[illegible]7173
2 31 [illegible]
4 13[illegible]135
5 13[illegible]13[illegible]
7 2[illegible] 23 31 [illegible] 41 [illegible] 54 [illegible]
10 1[illegible] 12 23 24 3 31 [illegible] 41 55 54 [illegible]
11 [illegible]
14 7 14 12 2[illegible] 27 [illegible] 43 42 55 [illegible] 17 [illegible]
15 7 [illegible] 13 [illegible] 27 2[illegible] 32 [illegible] 42 43 [illegible] 71[illegible]17[illegible]
16 114113
17 113114
18 11[illegible]11[illegible]
19 11[illegible]11[illegible]
20 12[illegible]121
21 12[illegible]12[illegible]
22 12[illegible]12[illegible]
23 12[illegible]12[illegible]
24 13 12[illegible]
25 12[illegible]13
26 13[illegible]134
27 134133
30 1[illegible] 2[illegible]17[illegible]17[illegible]
31 2[illegible] 1[illegible]17[illegible]17[illegible]
28 37 [illegible] 7[illegible] 15[illegible]151[illegible]13[illegible]17[illegible]
29 5[illegible] [illegible]6 77 [illegible]71[illegible]17[illegible]
32 1[illegible]1[illegible]
33 1[illegible]1[illegible]1

APPENDIX E

DATA SET DESCRIPTIONS

The following table shows which data set contains the subelements that supplement the GRASP/Army RPV Simulation MAIN Program.

	MP	W/O MP	MS1	MS2	MS3	AV1M
RPV 11	X					
RPV 12		X				
RPV 13	X				X	
RPV 14		X			X	
RPV 15	X		X			
RPV 16		X	X			
RPV 17	X			X		
RPV 18		X		X		
RPV 19	X				X	X
RPV 20		X			X	X
RPV 21	X		X			X
RPV 22		X	X			X
RPV 23	X			X		X
RPV 24		X		X		X

APPENDIX F

DETERMINATION OF DISTRIBUTIONS

In this model, Lockheed uses the exponential distribution in all calculations. In the GRASP Program this is used as an ERLANG-1 (K = 1), because theoretically the exponential distribution is a particular case of the ERLANG distribution when K = 1. Thus for the exponential distribution it is:

$$\text{Mean (MTBF)} = \frac{1}{\lambda}$$

The λ's supplied by Lockheed represent the failure rates per million (10^6) hours. Therefore, the mean if computed is 1/original λ is expressed in millions of hours; and $1/\lambda \times 10^6$ is the mean expressed in hours; and $1/\lambda \times 10^6 \times 60$ is the mean expressed in minutes. This last case is used to determine the failure rates since the RPV system model operates in minutes.

GCS Subsystems

<u>AVO Console</u>

$\lambda = 2634$

$$\text{Mean} = \frac{1}{2634} \times 10^6 \times 60 = 22779.04 \text{ min}$$

which is Parameter Set No. 16

<u>MPO Console</u>

$\lambda = 945$

$$\text{Mean} = \frac{1}{945} \times 10^6 \times 60 = 63492.06 \text{ min}$$

which is Parameter Set No. 17

<u>MC Console</u>

$\lambda = 1045$

$$\text{Mean} = \frac{1}{1045} \times 10^6 \times 60 = 57416.27 \text{ min}$$

which is Parameter Set No. 18

Navigation DPL. Console

$\lambda = 286$

$$\text{Mean} = \frac{1}{286} \times 10^6 \times 60 = 209790.2 \text{ min}$$

which is Parameter Set No. 19

Computer Signal-Processing Unit

$\lambda = 381$

$$\text{Mean} = \frac{1}{381} \times 10^6 \times 60 = 157480 \text{ min}$$

which is Parameter Set No. 20

AV Subsystem

Mission Payload

$\lambda = 5818$

$$\text{Mean} = \frac{1}{5818} \times 10^6 \times 60 = 10312.82 \text{ min}$$

which is Parameter Set No. 4

FCEP and FLT Sensor Packages

$\lambda = 512$

$$\text{Mean} = \frac{1}{512} \times 10^6 \times 60 = 117187.5 \text{ min}$$

which is Parameter Set No. 9

ARA

$\lambda = 261$

$$\text{Mean} = \frac{1}{261} \times 10^6 \times 60 = 229885.06 \text{ min}$$

which is Parameter Set No. 10

ADT

$\lambda = 809$

$$\text{Mean} = \frac{1}{809} \times 10^6 \times 60 = 74165.64 \text{ min}$$

which is Parameter Set No. 11

Baseline Electrical Power

$\lambda = 333$

$$\text{Mean} = \frac{1}{333} \times 10^6 \times 60 = 180180.18 \text{ min}$$

which is Parameter Set No. 12

Air Frame

$\lambda = 192$

$$\text{Mean} = \frac{1}{192} \times 10^6 \times 60 = 312500 \text{ min}$$

which is Parameter Set No. 13

APPENDIX G

MAINTENANCE SHELTER CONCEPTS (Diagram 8)

In the GRASP Simulation Program three different types of maintenance systems were used to try to describe different types of diagnostic testing techniques.

Concept 1: Options for entire system checkout. Possibility of AV being sent to MS in need of repair.

Concept 2: Model from a LMSC document (LMSC-D732866). Purpose: to see if GRASP is a useful tool in making direct modeling adaptations.

Concept 3: A model resembling a similar contract requirement in which 90% of the AV's are repaired and returned to service

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16. Abstract

This is a consolidation of the preliminary work done in the application of a General Reliability Analysis Simulation Program (GRASP) for the Lockheed Remotely Piloted Vehicle (RPV) system, being developed for the United States Army.

The model simulates the field operation of the RPV system. By using individual component reliabilities, the overall reliability of the RPV system is determined. The results of the simulations are given in operational days. The model represented is only a basis from which more detailed work could progress.

The RPV system in this model is based on preliminary specifications and estimated values. The scope of this report demonstrates the use of GRASP from basic system definition, to model input, and to model verification.

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